This document contains the appendices (A through J) to the following report prepared for EPA :

Non-groundwater Pathways, Human Health and Ecological Risk analysis for Fossil Fuel Combustion, Phase 2

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Appendix A

Physical and Chemical Properties for Constituents of Concern

Table A-1 Health Benchmarks for Metals of Concern in FFC Waste

Name	CAS	RfD (mg/kg/day)	Rfd Source	Oral CSF (mg/kg/day)-1	Oral CSF Source	RfC (mg/m3)	RfC Source	Inhalation URF (ug/m3)-1	Inhalation URF Source	Inhalation CSF (mg/kg/day)-1	Inhalation CSF Source
Aluminum	7429-90-5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lead	7439-92-1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nickel	7440-02-0	0.02	IRIS	NA	NA	NA	NA	0.00024	IRIS	0.84	HEAST
Silver	7440-22-4	0.005	IRIS	NA	NA	NA	NA	NA	NA	NA	NA
Thallium (I)	7440-28-0	0.00008	IRIS	NA	NA	NA	NA	NA	NA	NA	NA
Arsenic	7440-38-2	0.0003	IRIS	1.5	IRIS	NA	NA	0.0043	IRIS	15.05	calculated[b]
Barium	7440-39-3	0.07	IRIS	NA	NA	0.0005	HEAST	NA	NA	NA	NA
Beryllium	7440-41-7	0.005	HEAST	4.3[a]	IRIS	NA	NA	0.0024	IRIS	8.4	HEAST
Boron	7440-42-8	0.09	IRIS	NA	NA	0.02	HEAST	NA	NA	NA	NA
Cadmium	7440-43-9	0.001	IRIS	NA	NA	NA	NA	0.0018	IRIS	6.3	calculated[b]
Chromium VI	7440-47-3	0.005	IRIS	NA	NA	NA	NA	0.012	IRIS	42	calculated[b]
Cobalt	7440-48-4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Copper	7440-50-8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vanadium	7440-62-2	0.007	HEAST	NA	NA	NA	NA	NA	NA	NA	NA
Zinc	7440-66-6	0.3	IRIS	NA	NA	NA	NA	NA	NA	NA	NA
Selenium	7782-49-2	0.005	IRIS	NA	NA	NA	NA	NA	NA	NA	NA

a - Since the analysis was performed the oral CSF was removed from IRIS.
b - Inhalation CSF = Inhalation URF*3500

Table A-2 Chemical and Physical Properties for Metals of Concern in FFC Waste

Name	CAS	Soil Adsorption Coefficient (Koc) (mL/g)	Soil-Water Partition Coefficients (Kd) (mL/g)	Octanol-Water Partition Coefficient (Kow)	Henry's Law Constant (atm-m3/mol)	Diffusion Coefficient in Water (cm2/s)	Diffusion Coefficient in Air (cm2/s)	Molecular weight (g/mol)
Aluminum	7429-90-5	NA	1500	NA	NA	NA	NA	26.98
Lead	7439-92-1	NA	280000	NA	NA	NA	NA	207.20
Nickel	7440-02-0	NA	82	NA	NA	NA	NA	58.69
Silver	7440-22-4	NA	0	NA	NA	NA	NA	107.87
Thallium (I)	7440-28-0	NA	74	NA	NA	NA	NA	204.38
Arsenic	7440-38-2	NA	29	NA	NA	NA	NA	74.92
Barium	7440-39-3	NA	530	NA	NA	NA	NA	137.33
Beryllium	7440-41-7	NA	70	NA	NA	NA	NA	9.01
Boron	7440-42-8	NA	3	NA	NA	NA	NA	10.81
Cadmium	7440-43-9	NA	162	NA	NA	NA	NA	112.41
Chromium VI	7440-47-3	NA	18	NA	NA	NA	NA	52.00
Cobalt	7440-48-4	NA	45	NA	NA	NA	NA	58.93
Copper	7440-50-8	NA	22	NA	NA	NA	NA	63.55
Vanadium	7440-62-2	NA	50	NA	NA	NA	NA	50.94
Zinc	7440-66-6	NA	40	NA	NA	NA	NA	65.38
Selenium	7782-49-2	NA	4	NA	NA	NA	NA	78.96

Table A-3 Biotransfer and Bioaccumulation Values for Metals of Concern in FFC Waste

Name	CAS	Fw, Fraction of Wet Deposition Adhering to Plant Surface	Plant-Soil RCF-Root Veg (ug/g WW plant)/(ug/mL soil water)	Plant-Soil BCF-Leafy Veg (ug/g DW plant)/(ug/g soil)	Plant-Soil BCF-forage (ug/g DW plant)/(ug/g soil)	Plant-Soil BCF-grains (ug/g DW plant)/(ug/g soil)	Air-Plant Biotransfer Factor-leafy veg (ug/g DW plant)/(ug/g air)	Air-Plant Biotransfer Factor-forage (ug/g DW plant)/(ug/g air)	Biotransfer Factor- beef (day/kg)	Biotransfer Factor-dairy (day/kg)	BAFfish (L/kg body weight) (total)	BCFfish (L/kg) (dissolved)
Aluminum	7429-90-5	0.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lead	7439-92-1	0.6	9.0E-03	1.3E-05	1.3E-05	1.3E-05	NA	NA	3.0E-04	2.5E-04	NA	4.40E+01
Nickel	7440-02-0	0.6	8.0E-03	3.2E-02	1.1E-01	3.2E-02	NA	NA	6.0E-03	1.0E-03	NA	8.00E-01
Silver	7440-22-4	0.6	1.0E-01	4.0E-01	4.0E-01	4.0E-01	NA	NA	3.0E-03	2.0E-02	NA	0.00E+00
Thallium (I)	7440-28-0	0.6	4.0E-04	4.0E-03	4.0E-03	4.0E-03	NA	NA	4.0E-02	2.0E-03	NA	6.70E+01
Arsenic	7440-38-2	0.2	8.0E-03	3.6E-02	6.0E-02	3.6E-02	NA	NA	2.0E-03	6.0E-03	NA	3.50E+00
Barium	7440-39-3	0.6	1.5E-02	1.5E-01	1.5E-01	1.5E-01	NA	NA	1.5E-04	3.5E-04	NA	NA
Beryllium	7440-41-7	0.6	1.5E-03	1.0E-02	1.0E-02	1.0E-02	NA	NA	1.0E-03	9.0E-07	NA	1.90E+01
Boron	7440-42-8	0.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cadmium	7440-43-9	0.6	6.4E-02	3.6E-01	1.4E-01	3.6E-01	NA	NA	1.6E-04	1.0E-05	NA	1.87E+02
Chromium VI	7440-47-3	0.6	4.5E-03	7.5E-03	7.5E-03	7.5E-03	NA	NA	5.5E-03	1.5E-03	NA	1.00E+00
Cobalt	7440-48-4	0.6	7.0E-05	2.0E-02	2.0E-02	2.0E-02	NA	NA	2.0E-02	2.0E-03	NA	NA
Copper	7440-50-8	0.6	2.5E-01	4.0E-01	2.4E-02	4.0E-01	NA	NA	1.0E-02	1.5E-03	NA	0.00E+00
Vanadium	7440-62-2	0.6	3.0E-03	5.5E-03	5.5E-03	5.5E-03	NA	NA	2.5E-03	2.0E-03	NA	NA
Zinc	7440-66-6	0.6	4.4E-02	2.5E-01	9.6E-02	2.5E-01	NA	NA	1.2E-04	3.0E-05	NA	1.61E+02
Selenium	7782-49-2	0.2	2.2E-02	1.6E-02	6.0E-03	1.6E-02	NA	NA	3.0E-03	4.5E-03	NA	8.81E+01

Appendix B

Waste Characterization

Appendix B. Concentration Data Used for FFC Risk Assessment

Introduction

The following types of concentration data are used for the FFC risk assessment presented in this report:

- *Totals Data:* The solid portion of the waste matrix, such as ash or sludge.
- *Surface Impoundment Data:* Ambient water from a surface impoundment managing FFC wastes.
- *Leachate and Pore Water Data:* The leachate generated from solids. The leachate is measured by both laboratory testing (e.g., TCLP) and *in situ* measurements (i.e., pore water data provided by EPRI). It differs from surface impoundment data by being collected very close to, or within, the solid matrices.

This appendix discusses the first two types of data. The third is discussed in Appendix F to "Technical Background Document for the Supplemental Report to Congress on Remaining Fossil Fuel Combustion Wastes, Ground-Water Pathway Human Health Risk Assessment," draft final, April 1998.

Totals Data

Table B-1 presents an overview of the data sources used for FFC waste characterization for all constituents evaluated.

Table B-1. Source of Totals Data for FFC Wastes

Scenario	Data Source
Co-management coal combustion wastes: characterizing solid waste concentrations for all scenarios	EPRI Site Investigations (14 sites plus 2 earlier reports) that characterize samples of co-managed wastes
Oil combustion wastes: characterizing concentrations in solid wastes for all scenarios	EPRI oil ash database supplemented with one verification sample from Florida Power & Light
Fluidized bed combustion wastes: characterizing concentrations in solid wastes for all scenarios	CIBO data summary tables for FBC byproducts
Non-utility wastes: characterizing concentrations in solid wastes for all scenarios	Same as coal combustion co-management wastes

Coal Combustion Waste Co-Management Data: Solid Waste Characterization

Totals data from co-managed coal combustion wastes from the utility industry were compiled from 16 reports, each detailing site investigations from the late 1980s to early 1997. They include the 14 EPRI site investigations, plus two additional reports characterizing the co-management of FGD sludge with low volume wastes published by EPRI in 1994 (i.e., the "sodium based FGD sludge" and the "calcium based FGD sludge" reports). In total, characterization data representing 48 relevant samples from 18 sites are used. These data are summarized in Table B-2. The type of data represented are as follows:

- Fly ash co-managed with low volume wastes (13 samples)
- Bottom ash co-managed with low volume wastes (5 samples)
- Combined ash co-managed with low volume wastes (9 samples)
- FGD sludge co-managed with low volume wastes (16 samples)
- Other miscellaneous combinations of high and low volume wastes (5 samples).

In evaluating the concentration data, the following assumptions and procedures were used:

- Non-detects were assigned a value equal to one-half the detection limit.

- Multiple samples from an individual site were averaged to obtain up to 18 data points for each constituent (one for each site).

- From this distribution of 18 sites, a 50th and 95th percentile was determined. The 95th percentile always corresponded to the maximum (facility averaged) concentration for this data set.

<u>Oil Ash Data</u>

Oil ash characterization data is based on a spreadsheet provided by EPRI, supplemented with one EPA verification sample data from a Florida Power and Light (FP&L) facility. A total of 188 oil ash samples are available. Totals data for bottom ash (47 samples), fly ash (35 samples), and settling basin solids (88 samples) were compiled separately. The remaining 18 samples are comprised of miscellaneous wastes which were not included in the analysis (such wastes would, in any case, be represented by settling basin solids because they are typically discharged to a settling basin). Totals data for bottom ash, fly ash, and settling basin solids were compiled separately. In compiling data for each waste type, constituent concentrations in all samples representing the same waste type were averaged for a given facility. These average values were arrayed to develop relevant statistics, such as median and 95th percentile concentrations, for each constituent in each waste type. If a particular constituent was reported as not detected, a value equal to one-half the detection limit was used in the calculations.

Only totals data for settling basin solids are used in the analyses to date. These data are presented in Table B-3. The reason for considering this single waste type is as follows:

- Based on the EPRI Oil Ash report, a typical management practice for fly ash is hydraulic transport to a settling basin, followed by dredging and final disposal. Therefore, the characteristics of fly ash are expected to be represented by settling basin solids.

- With the exception of bottom ash, little characterization is available for the remaining wastes. As mentioned above, most or all of these waste streams are influents to a settling basin, where these wastes would become settling basin solids and therefore would be represented by SSB sludge characterization data.

- According to the EPRI oil ash report, bottom ash is typically not managed in settling basins and therefore bottom ash is not expected to be represented by settling basin solids characteristics. However, the bottom ash generation rate is much less than the settling basin solids generation rate, based on the oil ash report.

FBC Wastes

Data characterizing FBC wastes are available from a single source. In August 1996, the Council of Industrial Boiler Owners (CIBO) sent a survey to all operators of fluidized bed boilers for voluntary completion. This survey collected data detailing the design, fuel usage, waste generation, waste management practices, and waste composition of FBC boilers using fossil fuel. The survey results as they relate to ash composition are presented in "Report to the U.S. EPA on Fossil Fuel Combustion Byproducts from Fluidized Bed Boilers, November 1997." Survey responses are available from 38 facilities, representing 45 percent of the total number of facilities with at least one FBC unit. Totals analyses for three types of wastes are presented (fly ash, bed ash, and combined ash), although concentrations for only one waste type are presented here: combined ash. These statistics are taken directly from the CIBO printout (i.e., no comparison or adjustment was made using the bed ash or fly ash data). The data are reproduced in Table B-4. The reasons for assessing combined ash only, rather than or in addition to bed and fly ash, are as follows:

- By definition, combined ash is *a combination* of bed ash and fly ash. Therefore, the individual characteristics of fly ash and bed ash are represented in the combined ash.

- The predominant (but not exclusive) practice is for facilities to combine their bottom ash and fly ash prior to further management (CIBO, 1997b). However, because combined ash represents both bottom ash and fly ash, these segregated management practices are captured in the risk analysis by assessing combined ash.

Constituents reported as not detected were assigned a value by CIBO equal to one-half the detection limit. The 95th percentile was calculated by CIBO from a distribution of all samples regardless of the originating facility, which is slightly different than the method used in calculating the oil ash and comanagement data (where facility averaging is used).

Non-Utility Coal Combustion Wastes: Solid Waste Characterization

The same data used for utility coal combustion co-managed wastes are used here.

Surface Impoundment Data

Data characterizing surface impoundment pond waters are available for only one of the four FFC generating sectors: comanagement at coal fired utilities. Similar data are not available for surface impoundments managing oil combustion wastes, FBC waste, or non-utility wastes. Therefore the discussion below is exclusive to coal combustion waste comanagement in surface impoundments.

Data characterizing pond waters from the co-management of high and low volume coal combustion wastes are available from EPRI. Specifically, data are available for a total of 16 sites, although not all sites reported data for all constituents. The same data sources used in characterizing totals data were used to characterize surface impoundment data. Data are presented in Table B-5.

The purpose of summarizing these data is to represent ambient conditions in a pond. Therefore, decisions were made in what to consider an "ambient" water. Examples of such waters are standing water collected directly from the pond and pond effluents. Examples of waters not included are "raw" waste influents such as sluice waters and low volume wastes (which would be quickly diluted in the pond, or represent only very localized effects), and impoundments containing low volume wastes only (which are outside the scope of the study). A total of 59 pond samples from 16 sites were used as the basis for calculating the characterization data. The number of sample locations at each site ranged from 1 to 20. The samples include ponds managing fly ash, bottom ash, and/or FGD sludge in conjunction with low volume wastes.

In evaluating the concentration data, the following assumptions and procedures were used:

- Non-detects were assigned a value equal to one-half the detection limit.

- Multiple samples from an individual site were averaged to obtain up to 16 data points for each constituent (one for each site).

- From this distribution of 18 sites, a 50th and 95th percentile was determined. The 95th percentile always corresponded to the maximum (facility averaged) concentration for this data set.

- The sampling methodologies were not always consistent between sites. Most samples represented filtered water although no distinction was made in the data compilation. Specifically, some samples were identified as "total" (i.e., unfiltered) and others were identified as "dissolved" (i.e., filtered). Other samples were not explicitly identified as filtered or unfiltered, but are presumed to be filtered because most water samples collected by EPRI in their site investigations were filtered.

Table B-2. Co-managed Coal Combustion Wastes from Utilities: Totals Data from 18 Sites				
Analyte	Units	Maximum Concentration (95% Percentile Values)	Median Concentration	Number of Sites Reporting a Concentration
Al	ug/g	1.43e+05	6.28e+04	18
Ca	ug/g	2.60e+05	1.39e+05	18
Fe	ug/g	1.31e+05	5.68e+04	18
K	ug/g	2.34e+04	4.48e+03	18
Mn	ug/g	8.17e+02	2.93e+02	18
Mo	ug/g	4.31e+01	5.08e+00	18
S	ug/g	1.72e+05	1.87e+04	16
Si	ug/g	2.79e+05	1.29e+05	18
Sr	ug/g	4.76e+03	5.62e+02	17
Ag	ug/g	1.36e+01	6.17e+00	18
As	ug/g	1.54e+02	1.73e+01	18
Ba	ug/g	8.38e+03	7.71e+02	18
Cd	ug/g	2.37e+01	5.88e+00	18
Cr	ug/g	2.91e+02	5.94e+01	18
Cu	ug/g	1.55e+02	9.62e+01	18
Ni	ug/g	1.55e+02	5.98e+01	18
Pb	ug/g	1.52e+02	2.34e+01	18
Se	ug/g	3.24e+02	6.74e+00	18
V	ug/g	3.46e+02	6.83e+01	18
Zn	ug/g	8.56e+02	7.33e+01	18
Sb	ug/g	4.67e+01	6.07e+00	7
Be	ug/g	1.56e+01	8.38e+00	3
B	ug/g	4.17e+02	1.43e+02	5
Co	ug/g	4.16e+01	3.38e+01	4
Na	ug/g	1.25e+05	3.55e+03	7
Tl	ug/g	4.80e+01	2.25e+01	3
Mg	ug/g	1.53e+04	3.00e+03	7
Ti	ug/g	9.51e+03	9.51e+03	1
Source: EPRI Comanagement Reports.				

Table B-3. Oil-Fired Utility Waste Total Composition Data 1, 2
Solids Settling Basins (SSBs) 7

Waste Constituent	Total Composition (mg/kg)					
	No. of Facilities	No. of Non-Detections	Minimum	Mean	Median	Maximum and 95%ile
Aluminum	4	-	3500	33768	15619	100333
Antimony	1	-	66	66	66	66
Arsenic	17	1	6.28	210.4	16.05	1645.3
Barium	15	1	7.18	316.8	210	980
Boron	1	-	160	160	160	160
Cadmium	10	2	0.2	5.5	3.6	21.7
Calcium	12	-	534	47077	42350	122197
Chloride	12	-	150	5123	2286	19374
Chromium	14	-	13	456	354	1250
Cobalt	1	-	50.6	50.6	50.6	50.6
Copper	17	-	69	2254.5	528.5	16460
Fluoride	1	-	6.4	6.4	6.4	6.4
Iron	16	-	14000	92359	71817	247000
Lead	10	-	46	622.2	319	1773
Magnesium	12	-	1480	18938	11273	90000
Manganese	5	-	72	868.4	665	2600
Mercury	5	1	0.1083	0.221	0.2	0.38
Nickel	17	-	2410	9412	7150	32350
Nitrate	1	-	24.4	24.4	24.4	24.4
Phosphorus	1	-	130	130	130	130
Potassium	2	-	72.8	161.4	161.4	250
Selenium	6	-	0.79	13.4	9.9	34.96
Silver	6	4	**0.05**	3.9	2.7	9.7
Sodium	16	-	24.4	10490	8041	35000
Sulfate	12	-	5550	126745	69966	782798
Sulfide	2	1	**0.6**	235.3	235.3	470
Vanadium	19	-	880	31583	27895	69666.7
Zinc	17	-	74	829.7	437.1	4010

1 Data Source: EPRI, Oil Combustion By-Products Database, June 1997.

2 All measurements identified as below detection limits were assigned concentrations equal to one-half the detection limit.

7 Beryllium and tin tested for in five samples, but not detected.

Table B-4. FBC Byproducts: Totals Data for Combined Ash				
Analyte	Units	95% Percentile Concentration	Median Concentration	Number of Samples Used in Calculation
Al	ug/g	6.40e+04	2.46e+04	48
Sb	ug/g	5.17e+01	1.00e+01	45
As	ug/g	1.06e+02	1.31e+01	60
Ba	ug/g	6.50e+02	1.80e+02	57
Be	ug/g	9.50e+00	1.91e+00	12
B	ug/g	4.90e+01	2.11e+01	45
Cd	ug/g	5.00e+00	6.90e-01	50
Cr	ug/g	5.60e+01	3.45e+01	58
Co	ug/g	1.25e+01	4.60e+00	30
Cu	ug/g	2.49e+02	2.61e+01	56
Fe	ug/g	2.81e+04	1.28e+04	48
Pb	ug/g	6.70e+01	2.30e+01	57
Mn	ug/g	1.70e+02	6.18e+01	47
Hg	ug/g	2.78e+00	2.60e-01	57
Mo	ug/g	2.70e+01	9.96e+00	50
Ni	ug/g	5.30e+02	1.54e+01	59
K	ug/g	6.60e+03	4.14e+03	26
Se	ug/g	2.30e+01	4.00e+00	59
Ag	ug/g	5.00e+00	7.50e-01	48
Tl	ug/g	2.50e+01	5.19e+00	8
V	ug/g	5.00e+03	3.80e+01	11
Zn	ug/g	2.57e+02	1.99e+01	57
Source: FBC byproduct characterization data tables by CIBO.				

Table B-5. Concentrations in Impoundment Waters (all data are averaged across each facility)				
Parameter	Unit of Measure	Concentration		# Samples
		95th %ile	Median	
Aluminum	mg/L	5.11	0.74	13
Ammonia	mg/L	3.72	0.116	8
Antimony	mg/L	0.137	0.118	2
Arsenic	mg/L	0.55	0.0201	15
Barium	mg/L	0.712	0.134	14
Beryllium	mg/L	0.001	0.001	2
Boron	mg/L	460	5.67	16
Bromide	mg/L	5680	1.67	13
Cadmium	mg/L	0.25	0.0089	14
Calcium	mg/L	1020	225	16
Chloride	mg/L	21200	127	16
Chromium	mg/L	0.4	0.0112	15
Chromium, hexavalent	mg/L	0.0267	0.0267	1
Cobalt	mg/L	0.01	0.0075	2
Copper	mg/L	0.39	0.0077	11
Organic Carbon	mg/L	270	7.01	12
Ferric Iron	mg/L	0.0792	0.0384	3
Ferrous Iron	mg/L	0.07	0.05	3
Fluoride	mg/L	379	0.834	14
Inorganic Carbon	mg/L	120	17.5	11
Iron	mg/L	2.70	0.025	15
Lead	mg/L	0.25	0.0135	13
Magnesium	mg/L	1150	74.8	16
Manganese	mg/L	3.4	0.12	15
Mercury	mg/L	0.0015	0.001	2
Molybdenum	mg/L	0.5	0.188	15
Nickel	mg/L	0.6	0.0239	14
Nitrate	mg/L	1400	2.56	14
Nitrite	mg/L	6	0.227	12
Oxalate	mg/L	0.1	0.07	2
pH	units	10.1	8.4	15
Phosphate	mg/L	1500	0.437	14
Potassium	mg/L	1080	20.4	16
Redox Potential, Eh	mV	491	271	15
Selenium	mg/L	7.8	0.0402	13
Silicon	mg/L	34	4.39	14
Silver	mg/L	0.005	0.0044	3
Sodium	mg/L	61200	183	16

Table B-5. Concentrations in Impoundment Waters (all data are averaged across each facility)				
Parameter	Unit of Measure	Concentration		# Samples
		95th %ile	Median	
Specific conductance @ 25C	micromhos/cm	70400	742.75	10
Strontium	mg/L	30.05597	4.078875	14
Sulfate	mg/L	123000	2037.733	16
Sulfide	mg/L	1.53	0.5	3
Sulfite	mg/L	1070	1.760417	12
Sulfur	mg/L	4292.375	375.8911	8
Thallium	mg/L	0.05	0.02625	2
Thiosulfate Ion	mg/L	3370	0.2375	10
Uranium	mg/L	11	11	1
Vanadium	mg/L	0.8	0.03725	14
Zinc	mg/L	0.67	0.025	15
Purgeable Organics	mg/L	1.401613	1.401613	1
Alpha	pCi/L	4	4	1
Radium 226	pCi/L	0.3	0.3	1
Radium 228	pCi/L	0.5	0.5	1
Radon-222	mg/L	250	250	1
Hardness	mg/L	1121.524	770.7619	2
Temperature	EF	84.6	77.7	3
Total Dissolved Solids	mg/L	32500	1841.081	4
Bicarbonate	mg/L	75.58333	75.58333	1
Carbonate	mg/L	12	6.25	2
Hydroxide	mg/L	0.5	0.5	1
Alkalinity	mg/L	230	146	5
Source: EPRI Site Investigation reports.				

Appendix C

Overland Transport Model

Appendix C

Overland Transport Models

Methodology

The Universal Soil Loss Equation (USLE) is an empirical erosion model originally designed to estimate long-term average soil erosion losses to a nearby waterbody from an agricultural field having uniform slope, soil type, vegetative cover, and erosion-control practices. In the risk assessment, the USLE was used to estimate the mass of soil lost per year per unit area from a waste source and deposited directly onto the adjacent receptor site. A fixed sediment delivery ratio was used to estimate the percentage of eroded soil that ultimately reached the receptor site. The quantity of soil eroded from the waste source and deposited directly on each receptor site (agricultural field, residential lot, home garden) was estimated independently of soil eroded from the waste source and deposited into the nearest surface waterbody.

The USLE was modified to estimate soil erosion and overland transport of sediment from waste sources across intervening areas to nearby waterbodies by evaluating this process in an integrated setting (Beaulieu et al., 1996). Overland transport of sediment from waste sources to receptor locations is estimated independently from transport from the waste source to the waterbody. Because the USLE equation estimates only soil erosion to waterbodies, the receptor location is considered to be located between the waste source and the waterbody. The area including the waste source, the receptor site, and the intervening area is considered for the purposes of the analysis to be an independent drainage subbasin. The soil erosion load from the subbasin to the waterbody is estimated using a distance-based sediment delivery ratio and the sediment not reaching the waterbody is considered to be deposited evenly over the area of the subbasin. Thus, using mass balance equations, contributions to the constituent concentrations of the waterbody and of the receptor soil may be estimated. The equations implementing the concept of the integrated setting are based on the following assumptions:

- The area of the management unit and the area between the management unit and the nearest waterbody, including the receptor site, make up a discrete drainage subbasin. These areas are shown in the main body of this report.

- The sediment delivery ratio (SD_{SB}) and the soil loss rate per unit area are assumed to be constant for all areas within the subbasin.

- The amount of soil deposited onto the receptor site through soil erosion is estimated by assuming that the fraction of soil that does not reach the waterbody remains in the subbasin.

- The entire subbasin drainage system is assumed to be at steady-state. Consequently, steady-state soil concentrations for the different subareas (e.g., receptor site, surrounding area) can be calculated using a mass balance approach.

- The soils within the watershed are assumed (on the average) to have the same soil properties (e.g., bulk density, soil moisture content), a reasonable assumption for areas with similar irrigation rates with infrequent tilling.

- The soil/constituent movement within the entire watershed is evaluated separately from the soil/constituent movement that occurs in the drainage subbasin. Only air deposition of constituents contributes to the constituent concentrations in soil outside the subbasin. The contribution of each area within the watershed to the constituent concentration in the waterbody is estimated independently and summed to estimate the total waterbody concentration.

- No contributions to constituent concentrations are assumed to occur from sources other than the waste source within the subbasin.

Table C-1 lists the modified equations for overland transport used to implement the integrated setting approach to soil erosion and indicates if these equations have been changed or added since the proposed rule. The equations are presented in detail in Appendix E and Appendix F.

Soil Load from Waste Source to Receptor Site

The mass of eroded soil (soil load) from the waste source to the receptor site ($SL_{O,F}$) is a major input required to calculate the receptor site soil constituent concentration (C_F). The receptor site (residential plot, home garden, or agricultural field) soil concentrations are used to estimate risk through the soil ingestion pathway for all scenarios and through the food chain pathways (e.g., aboveground and belowground produce) for the home gardener and subsistence farmer scenarios. By assuming that the probability of soil redeposition is equivalent for all areas within the subbasin (i.e., the waste source, intervening area, and the receptor site), the amount of contaminated soil that erodes onto any area can be calculated by using a simple ratio of the area of concern to the total area for soil deposition:

$$DS_{0,F} = X_{c,s} \times A_s \times (1-SD_{SB}) \times SF_{0,F} \qquad \text{(C-1)}$$

Table C-1. Guide to Modified Equations for Overland Transport (bolded parameter are calculated using indented parameters)

Parameter	Definition
L_T	**Total constituent load to waterbody**
L_E	Constituent load via soil erosion to waterbody
L_R	Constituent load from pervious runoff to waterbody
L_E	**Constituent load via soil erosion to waterbody**
X_e	Unit soil loss
SD_{WS}	Sediment delivery ratio for watershed
2	Soil volumetric water content
$S_{c,erode}$	Average constituent concentration based on erosion
SD_{SB}	Sediment delivery ratio for subbasin
D_{WS}	Sediment delivery ratio for watershed
$A_{B/Surr}$	Area of buffer and surrounding area
C_F	Constituent concentration in offsite field
$C_{B/Surr}$	Constituent concentration in buffer and surrounding
C_{WS}	Constituent concentration in watershed
L_R	**Constituent load from pervious runoff to waterbody**
2	Soil volumetric water content
$S_{c,run}$	Average constituent concentration based on area
$A_{B/Surr}$	Area of buffer and surrounding area
C_F	Constituent concentration in offsite field
$C_{B/Surr}$	Constituent concentration in buffer and surrounding
C_{WS}	Constituent concentration in watershed
C_F	**Constituent concentration in offsite field**
$SL_{O,F}$	Soil load from site to offsite field
X_e	Unit soil loss
SD_{SB}	Sediment delivery ratio for subbasin
$A_{B/Surr}$	Area of buffer and surrounding area
$SF = SF_{O,F}$	Scaling factor
$A = A_S$	Area of source
$SL_{B,F}$	Soil load from buffer to offsite field

(continued)

Table C-1. (continued)

Parameter	Definition
X_e	Unit soil loss
SD_{SB}	Sediment delivery ratio for subbasin
$A_{B/Surr}$	Area of buffer and surrounding area
$SF = SF_{B,F}$	Scaling factor
$A = A_B$	Area of buffer
$C_{B/Surr}$	Constituent concentration in buffer and surrounding
$Ds_{(1),F}$	Aerial deposition rate term
ks_F	Constituent loss constant for offsite field
ksl	Loss constant due to leaching
2	Soil volumetric water content
kse	Loss constant due to erosion
X_e	Unit soil loss
SD_{SB}	Sediment delivery ratio for subbasin
$A_{B/Surr}$	Area of buffer and surrounding area
2	Soil volumetric water content
$CF = CF_F$	Correction factor
A_{BF}	Area between field and waterbody
ksr	Loss constant due to runoff
2	Soil volumetric water content
ksv	Loss constant due to volatilization
$A = A_F$	Area of offsite field
M_F	Mass of soil within mixing depth of offsite field
$A = A_F$	Area of offsite field
$\mathbf{C_{B/Surr}}$	**Concentration in buffer and surrounding area**
$SL_{O,B/Surr}$	Soil load to buffer and surrounding area
X_e	Unit soil loss
SD_{SB}	Sediment delivery ratio for subbasin
$A_{B/Surr}$	Area of buffer and surrounding area
$SF = SF_{O,B/Surr}$	Scaling factor
$A = A_S$	Area of buffer
$Ds_{(1),B/Surr}$	Aerial deposition rate term

(continued)

Table C-1. (continued)

Parameter	Definition
$ks_{B/Surr}$	Constituent loss constant for buffer and surrounding
ksl	Loss constant due to leaching
2	Soil volumetric water content
kse	Loss constant due to erosion
X_e	Unit soil loss
SD_{SB}	Sediment delivery ratio for subbasin
$A_{B/Surr}$	Area of buffer and surrounding area
2	Soil volumetric water content
$CF = CF_{B/Surr}$	Correction factor
ksr	Loss constant due to runoff
2	Soil volumetric water content
ksv	Loss constant due to volatilization
$A = A_{B/Surr}$	Area of buffer and surrounding
$M_{B/Surr}$	Mass of soil within mixing depth of buffer/surround
$A = A_{B/Surr}$	Area of buffer and surrounding
C_{WS}	**Constituent concentration in watershed**
$Ds_{(1),WS}$	Aerial deposition rate term
ks_{WS}	Constituent loss constant for watershed
ksl	Loss constant due to leaching
2	Soil volumetric water content
kse	Loss constant due to erosion
X_e	Unit soil loss
SD_{WS}	Sediment delivery ratio for watershed
2	Soil volumetric water content
$CF = CF_{WS}$	Correction factor
ksr	Loss constant due to runoff
2	Soil volumetric water content
ksv	Loss constant due to volatilization
$A = A_{WS}$	Area of watershed

where

$DS_{0,F}$	=	soil delivery rate from source (waste source) to receptor (kg/yr)
$X_{c,s}$	=	unit soil loss rate from waste source (kg/m^2-yr)
A_S	=	area of the waste source (m^2)
SD_{SB}	=	sediment delivery ratio of the subbasin to the nearest waterbody (unitless)
$SF_{0,F}$	=	deposition area scaling factor (m^2/m^2)
	=	ratio of the receiving field area to the entire area available for deposition
	=	$A_F/(A_S + A_{B/Surr} + A_F)$
A_F	=	area of the receptor site (m^2)
$A_{B/Surr}$	=	area of the buffer and surrounding areas within the subbasin (m^2).

Total Constituent Load to Waterbody

The total load to the waterbody (L_T) is the sum of the constituent load via erosion (L_E) and the constituent load from pervious runoff (L_R). The total load to the waterbody is used to estimate risk to the fisher from the ingestion of fish. The estimation of L_E requires the calculation of a weighted average constituent concentration in watershed soils based on the eroded soil contribution ($S_{c,erode}$), and the L_R term requires the calculation of a weighted average constituent concentration based on the pervious runoff contribution ($S_{c,run}$). The weighted average constituent concentration represents the effective watershed soil concentration based on contributions from the subbasin and the remainder of the watershed. Most important, the weighted average concentration accounts for the differences in constituent concentrations in the different areas within the watershed. The calculation of L_T requires constituent concentrations for each of the following areas within the watershed: the source (waste source), the receptor site, the buffer and surrounding area, and the watershed area outside the drainage subbasin. For the watershed soils outside the subbasin, it is assumed that constituents reach the watershed solely via air deposition (i.e., no erosion component).

Calculation of L_T requires constituent concentrations for each of the following areas within the watershed: the source (waste source); the offsite field, the buffer, and surrounding area within the subbasin); and the watershed area outside the drainage subbasin. If we consider the erosion load (L_E) to the surface waterbody for each of these areas individually, the equation may be written as:

$$\begin{aligned} L_E = {} & [X_{e,SB} \times ER \times SD_{SB} \times A_0 \times C_0 \times (\frac{Kd_s\ BD}{\theta + Kd_s\ BD}) \times 0.001] + \\ & [X_{e,SB} \times ER \times SD_{SB} \times A_F \times C_F \times (\frac{Kd_s\ BD}{\theta + Kd_s\ BD}) \times 0.001] + \\ & [X_{e,SB} \times ER \times SD_{SB} \times A_{B/Surr} \times C_{B/Surr} \times (\frac{Kd_s\ BD}{\theta + Kd_s\ BD}) \times 0.001] + \\ & [X_e \times ER \times SD_{WS} \times [A_{WS} - (A_0 + A_F + A_{B/Surr})] \times C_{WS} \times (\frac{Kd_s\ BD}{\theta + Kd_s\ BD}) \times 0.001] \end{aligned} \tag{C-2}$$

where

L_E	=	constituent load to watershed due to erosion (g/yr)
$X_{e,SB}$	=	unit soil loss in subbasin (kg/m^2/yr)
ER	=	enrichment ratio
SD_{SB}	=	sediment delivery ratio for subbasin
A_0	=	area of source (m^2)
C_0	=	constituent concentration at the source (mg/kg)
Kd_s	=	soil water partition coefficient (L/kg)
BD	=	bulk density of soil (g/cm^3)
2	=	volumetric soil content of soil (cm^3/cm^3)
0.001	=	unit conversion factor ([g/kg]/[mg/kg]).
A_F	=	area of receptor field (m^2)
C_F	=	constituent concentration in receptor site field (mg/kg)
$A_{B/Surr}$	=	area of buffer and surrounding area (m^2)
$C_{B/Surr}$	=	constituent concentration in buffer and surrounding area (mg/kg)
X_e	=	unit soil loss in watershed outside of subbasin (kg/m^2/yr)
SD_{SB}	=	sediment delivery ratio for watershed (unitless)
A_{WS}	=	area of entire watershed (m^2)
C_{WS}	=	constituent concentration in watershed soils outside of subbasin (mg/kg).

The enrichment ratio (ER) represents the reality that erosion favors the lighter soil particles, which have higher surface-area-to-volume ratios and are higher in organic matter content. Therefore, concentrations of organic constituents, which are a function of organic carbon content of sorbing media, would be expected to be higher in eroded soil then in in situ soil. This factor is generally assigned values in the range of 1 to 5. A value of 3 for organic contaminants and a value of 1 for metals would be reasonable first estimates (U.S. EPA, 1994).

Alternatively, this equation can be written in terms of an average weighted soil concentration for the watershed that results in the same constituent load as a function of erosion and sediment delivery. The $S_{c,erode}$ term shown at the end of Equation C-3 reflects this modification:

$$L_E \text{ ' } [X_e \times ER \times SD_{WS} \times A_{WS} \times (\frac{Kd_s\ BD}{2 \ \% \ Kd_s\ BD}) \times 0.001] \times S_{c,erode} \qquad \text{(C-3)}$$

L_T also requires the constituent load from pervious runoff (L_R). The L_R term is calculated using equation C-4.

$$L_R \text{ ' } R \times (A_{ws} \ \& \ A_I) \times \frac{S_c \times BD}{2 \ \% \ Kd_s \times BD} \times 0.01 \qquad \text{(C-4)}$$

where

L_R	=	pervious surface runoff load (g/yr)
R	=	average annual surface runoff (cm/yr)
A_{ws}	=	area of entire watershed (m^2)
A_I	=	impervious watershed area receiving constituent deposition (m^2)
S_c	=	weighted average constituent concentration in total watershed soils (watershed and sub-basin) based on surface area (mg/kg)
BD	=	soil bulk density (g/cm^3)
θ	=	volumetric soil content of soil (cm^3/cm^3)
Kd_s	=	soil water partition coefficient (L/kg) or (cm^3/g)
0.01	=	units conversion factor ($kg\text{-}cm^2/mg\text{-}m^2$).

Assuming that the ratio of pervious and impervious soils is the same for each of the designated areas, a correction for areas that do not erode (streets, rocks, etc.) can be added to Equation C-3 by replacing A_{WS} with A_{WS} - A_I , where A_I equals the total impervious area in the watershed. Setting the L_R equal to each other in the previous two equations and solving for $S_{c,erode}$ yields:

$$S_{c,erode} = \frac{(X_{e,SB} \times A_s \times C_0 \times SD_{SB}) + (X_{e,SB} \times A_{B/Surr} \times C_{B/Surr} \times SD_{SB}) + (X_{e,SB} \times A_F \times C_F \times SD_{SB})}{X_e \times SD_{WS} \times A_{WS}} + \frac{\{[A_{WS} - (A_0 + A_F + A_{B/Surr})] \times C_{WS}\}}{A_{WS}} \qquad \text{(C-5)}$$

Equation C-5 accounts for differences in the sediment delivery ratios (SD), surface areas (A), and mixing depths (Z) for discrete areas of the watershed (i.e., source, receptor field, buffer/ surrounding areas, and the remaining watershed). Similarly, the weighted average for runoff losses (ksr) was derived using the areas for various watershed components (e.g., receptor site field, watershed outside drainage subbasin); however, different sediment delivery ratios were not required because soils in the area were considered to be similar and the slope was considered uniform. It was possible to generate simple area-based weighting factors because the rainfall runoff per unit area was assumed to be constant for the entire watershed area.

Constituent Concentrations in Various Watershed Components

The constituent concentrations for the receptor site field (C_F), the buffer and surrounding area ($C_{B/Surr}$), and the watershed area outside of the drainage subbasin (C_{WS}) are required to solve $S_{c,erode}$. As suggested previously, a mass balance approach was used to calculate the constituent concentrations for all watershed components. For the receptor site field, the mass balance equation is given by:

$$M_F\,(dC_F/dt) = [C_0\,SL_{0,F} + (M_F\,Ds_{(1),F})] + (SL_{B,F}\,C_{B/Surr}) - (M_F\,ks_F\,C_F) \qquad \text{(C-6)}$$

where

M_F	=	mass of the field (kg)
C_F	=	constituent concentration in the receptor site field (mg/kg)
$SL_{0,F}$	=	soil load from source to the field (kg/yr)
$Ds_{(1),F}$	=	air deposition rate from source to the field (mg/kg-yr)
$SL_{B,F}$	=	soil load from buffer to the field (kg/yr)
ks_F	=	constituent loss rate coefficient for the field (per yr).

At steady state, this equation can be solved for the constituent concentration in the receptor site field as follows:

$$C_F = [(C_0\ SL_{0,F} + M_F\ Ds_{(1),F}) + (SL_{B,F}\ C_{B/Surr})] / (M_F\ ks_F) \tag{C-7}$$

As with the constituent concentration in the receptor site field, the concentration in the buffer and surrounding area is given by:

$$M_{B/Surr}(dC_{B/Surr} / dt) = (SL_{0,B/surr}\ C_0) + [M_{B/Surr}\ (Ds_{(1),B/Surr} - ks_{B/Surr}\ C_{B/Surr})] \tag{C-8}$$

where

$M_{B/Surr}$	=	mass of the buffer and surrounding area (kg)
$C_{B/Surr}$	=	constituent concentration in the buffer and surrounding area (mg/kg)
$SL_{0,B/Surr}$	=	soil load from source to buffer/surrounding areas (kg/yr)
C_0	=	soil constituent concentration at the source (mg/kg)
$Ds_{(1),B/Surr}$	=	air deposition rate from source to buffer and surrounding area (mg/kg-yr)
$ks_{B/Surr}$	=	constituent loss rate coefficient for the buffer/surrounding area (per/yr).

At steady state, this equation may be solved for $C_{B/Surr}$ as follows:

$$C_{B/Surr} = (C_0\ SL_{0,B/Surr} + M_{B/Surr}\ Ds_{(1),B/Surr}) / (M_{B/Surr}\ ks_{B/Surr})\ . \tag{C-9}$$

For the watershed soils outside of the subbasin, we assumed that constituents reached the watershed solely via air deposition (i.e., no erosion component). Using similar mass balance and steady-state assumptions, the constituent concentration in watershed soils outside the subbasin may be calculated using:

$$C_{WS} = Ds_{(1),WS} / ks_{WS} \tag{C-10}$$

where

C_{WS} = soil constituent concentration in the watershed (mg/kg)
$Ds_{(1),WS}$ = air deposition rate from source to the watershed (mg/kg/yr)
ks_{WS} = constituent loss rate coefficient for the watershed (per yr).

Summary

The equations and default input parameter values used to calculate receptor site soil concentrations and the waterbody concentrations of constituents of concern, including the revised overland transport pathways, are presented in Appendix E and Appendix F.

Contaminated particles are transported from the waste source to receptor sites via air deposition as well as runoff/erosion. For the revised integrated setting analysis, mass balance was applied for each area of interest (e.g., buffer area between source and receptor site, receptor site, or surrounding area). Consequently, the respective air deposition value for each area of interest is included in the evaluation of the mass balance. The air deposition over the entire subbasin area was considered to be uniform and equal to the air deposition modeled for the receptor site.

References

Beaulieu, S. M., J. Coburn, and E. C. Hubal. 1996. Memorandum to Pat Jennings, U.S. EPA Office of Solid Waste. Research Triangle Institute. Re: Modified Soil Erosion/Runoff Equations. Research Triangle Park, NC. September 30.

U.S. EPA (Environmental Protection Agency). 1994. Estimating Exposures to Dioxinlike Compounds. Volumes I-III: Site-Specific Assessment Procedures. EPA/600/6-88/005C. Office of Research and Development, Washington, DC. June.

Appendix D

ISCST3 Air Dispersion Model

Appendix D

ISCST3 Air Dispersion Model

Air dispersion modeling will be conducted with the EPA's Industrial Source Complex Short Term, version 96113 (ISCST3). ISCST3 is a Gaussian plume model that can simulate both wet and dry deposition and plume depletion. The ISCST3 outputs are used to estimate the particulate air concentrations and deposition rates needed to develop risk estimates associated with exposures attributable to fugitive emissions released from ground-based, area sources. The EPA's ISCST3 model is applicable in simple, intermediate, and complex terrains. However, as discussed in Volume II of the ISCST3 User's Guide (U.S. EPA, 1995a) the complex terrain screening algorithms do not apply to area sources such as the emission sources being investigated as part of this analysis. Consequently, regardless of the location being modeled, receptor elevations were not specified in the ISCST3 input files. The ISCST3 model will be run using "default" model options specified in the *Guideline on Air Quality Models* (U.S. EPA, 1993).

Determination of Environmental Setting Required for Air Modeling

Before beginning the air dispersion modeling, the area around a facility should be investigated to identify the types of land uses in the area, and to select water bodies to model exposures to contaminants through fish ingestion. Characterizing these environmental settings is crucial in the risk assessment process. For the generic setting that will be used in this analysis the surrounding land use will be defined as agricultural.

Another environmental setting characterization that is important for the air dispersion portion of the fate and transport modeling is the roughness length. The roughness length is a measure of the variation in height of individual elements on the landscape such as trees and buildings. Roughness height values for various land use types are presented in Appendix B of the *PCRAMMET User's Guide* (U.S. EPA, 1995b) for the ISCST3 Model.

Preparing Meteorological Data

ISCST3 requires a variety of meteorologic data as input. For each location modeled, 5 years of surface and upper air data will be obtained to determine long-term average air dispersion and deposition estimates. Surface data will be obtained from the SAMSON CD-ROM for each National Weather Service station located in a location of interest. These data include 5 years of hourly observations of the following meteorologic parameters: opaque sky, temperature, wind direction, windspeed, ceiling height, present weather, station pressure, and precipitation type and amount. The corresponding upper air data will be obtained from EPA's SCRAM bulletin board and will be paired with the surface data for air dispersion modeling through the use of the meteorologic preprocessor PCRAMMET. PCRAMMET pairs the surface data with the upper air data to create a meteorologic file that contains hourly windspeed, wind direction, atmospheric stability class, temperature, and mixing height. The preprocessor also requires additional inputs based on site-specific land use data. PCRAMMET inputs were derived as recommended in the *PCRAMMET User's Guide* based on conservative assumptions.

Table D-1 identifies the particle size distribution and the associated scavenging coefficients that will be used in conducting air dispersion modeling for this analysis. The scavenging coefficients associated with the particle size distribution were obtained from Jindal and Heinhold (1991). Liquid and frozen scavenging coefficients were set equal (PEI, 1986).

Table D-1. Particle Size Distribution and Scavenging Coefficients

Particle Size Diameter (μm)	Weight Distribution (Fraction)	Liquid and Frozen Scavenging Coefficients (h/mm-s)
5.0	0.50	3.9E-4
20.0	0.50	6.7E-4

Although wet scavenging of vapors depends on the properties of the chemicals involved, not enough data are available to develop chemical-specific scavenging coefficients adequately at this time. Therefore, gases were assumed to be scavenged at the rate of small particles whose behavior in the atmosphere is assumed to be more influenced by the molecular processes that affect gases than the physical processes that often dominate behavior of larger particles. The value 1.7e-4 (h/mm-s) for the gas scavenging coefficient was also taken from Jindal and Reinhold (1991).

Preparing ISCST3 Input Files

A thorough discussion of how to prepare the input files for ISCST3 can be found in the ISC3 User's Guide (U.S. EPA, 1995a). The model and the User's Guide are available for downloading from the SCRAM BBS. ISCST3 requires site-specific inputs for source parameters, receptor locations, meteorological data, and terrain features. The model is setup through the use of a control file. The control file is divided into the sections listed below that are identified in the control file by two-letter keywords.

Section	Keyword
Control	CO
Source	SO
Receptor	RE
Meteorology	ME
Terrain	TG
Output	OU

Specific directions for running the ISCST3 model are provided in the ISC3 User's Guide.

The ISCST3 air model is run using a unit emission rate of 1 microgram per second per square meter. Adjustments for facility-specific emission rates occur later in the indirect modeling process. However, the model does require a limited amount of facility-specific information to estimate air concentrations and deposition rates. The facility-specific inputs include emission source characteristics and particle size distribution data.

References Cited

Jindal, M. and D. Reinhold. 1991. Development of Particulate Scavenging Coefficients to Model Wet Deposition from Industrial Combustion Sources. Paper 91-59.7. Annual Meeting - Exhibition of Air and Waste Management Association, Vancouver, BC. June 16-21, 1991.

PEI Associates, Inc. 1986. *Air Quality Modeling Analysis of Municipal Waste Combustors*. Prepared for the U.S. Environmental Protection Agency, Monitoring and Data Analysis Division, Research Triangle Park, NC.

U.S. Environmental Protection Agency. 1995a. *User's Guide for the Industrial Source Complex Dispersion Models*. Office of Air Quality Planning and Standards, RTP, NC. Draft.

U.S. Environmental Protection Agency. 1995b. *PCRAMMET User's Guide.* Office of Air Quality Planning and Standards, RTP, NC. Draft.

U.S. Environmental Protection Agency. 1993. *Guideline on Air Quality Models.* Office of Air Quality Planning and Standards, Research Triangle Park, NC.

Appendix E

Landfill and Surface Impoundment Equations

Table E-1.1. Constituent Concentration In Residential Plot Due to Erosion

Adult Resident Exposure Scenario

$$C_R = \frac{SL_{0,F} \times C_0 \times ER}{ks_R \times M_R} + \frac{SL_{B,F} \times C_{B/Surr} \times ER}{M_R \times ks_R} + \frac{Ds_{(1)R}}{ks_R}$$

Parameter	Definition	Central Tendency	High End
C_R	Constituent concentation at residential plot (mg/kg)		
$SL_{0,F}$	Soil load delivered to off-site location for material originating in source area (kg/yr)	Calculated (see Table E-1.2.)	
$SL_{B,F}$	Soil load delivered to off-site location for material originating in buffer area (kg/yr)	Calculated (see Table E-1.7.)	
$C_{B/Surr}$	Constituent concentration in buffer and surrounding areas (mg/kg)	Calculated (see Table E-1.11.)	
$Ds_{(1),R}$	Deposition term for the residential plot (mg/kg.yr)	Calculated (see Table E-1.24.)	
C_0	Source contaminant concentration (mg/kg)	Chemical-specific	
ks_R	Constituent loss constant from the residential plot (1/yr)	Calculated (see Table E-1.25.)	
M_R	Mass of soil in mixing depth of residential plot (kg)	Calculated (see Table E-1.32.)	
ER	Constituent enrichment ratio (unitless)	Metals = 1	

Description

This equation is used to calculate the mass of constituent deposited onto residential plot as a result of erosion from the source.

Table E-1.2. Soil Load Delivered to Off-Site Location for Material Originating from Source Area

All Exposure Scenarios			
$$SL_{0,F} = X_{e,S} \times A_S \times (1 - SD_{SB}) \times SF_{0,F}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
$SL_{0,F}$	Soil load delivered to off-site location for material originating from source area (kg/yr)		
$X_{e,s}$	Unit soil loss from source (kg/m^2-yr)	Calculated (see Table E-1.3.)	
A_S	Area of source (m^2)	Source-specific	
SD_{SB}	Sediment delivery ratio for sub-basin (unitless)	Calculated (see Table E-1.4.)	
$SF_{O,F}$	Scaling factor	Calculated (see Table E-1.6.)	
Description			
This equation is used to calculate the load of eroded soil originating from the source that is deposited onto the off-site location of interest.			

Table E-1.3. Universal Soil Loss Equation (USLE) for the Source Area

All Exposure Scenarios			
$$X_{e,S} = R_S \times K_S \times LS_S \times C_S \times P_S \times \frac{907.18}{4047}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
$X_{e,S}$	Unit soil loss from the source ($kg/m^2/yr$)		
R_S	USLE rainfall (or erosivity) factor (1/yr)	Met Specific (See Table 2-1 of Report)	
K_S	USLE erodibility factor (ton/acre)	0.3	
LS_S	USLE length-slope factor (unitless)	1.5	
C_S	USLE cover management factor (unitless)	0.15	
P_S	USLE supporting practice factor (unitless)	1	
907.18	Conversion factor (kg/ton)		
4047	Conversion factor (m^2/acre)		
Description			
This equation calculates the soil loss rate from the source, using the Universal Soil Loss Equation; the result is used in the soil erosion load equation.			

Table E-1.4. Sediment Delivery Ratio

All Exposure Scenarios			
$$SD_{SB} = a \times (A_S + A_{B/Surr} + A_F)^{-b}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
SD_{SB}	Sediment delivery ratio for sub-basin (unitless)		
a	Empirical intercept coefficient	Depends on sub-basin area; see table below	
A_S	Area of source (m^2)	Waste management scenario specific	
$A_{B/Surr}$	Area of buffer and surrounding areas (m^2)	Calculated (see Table E-1.5.)	
A_F	Area of off-site location of interest (m^2)	Ag. field = 902,450 Residential plot or home garden = 5,100	
b	Empirical slope coefficient	0.125	
Description			
This equation calculates the sediment delivery ratio for the sub-basin; the result is used in the soil erosion load equation.			

Values for Empirical Intercept Coefficient, a

Sub-basin (A_s+$A_{B/Surr}$+A_F)	"a" coefficient (unitless)
≤ 0.1	2.1
1	1.9
10	1.4
100	1.2
1,000	0.6
1 sq. mile = 2.59×10^6 m^2	

Table E-1.5. Buffer and Surrounding Areas

All Exposure Scenarios

$$A_{B/Surr} = d_b \times \sqrt{A_F} \quad \text{if} \quad A_F > A_S$$

$$A_{B/Surr} = \left(\sqrt{A_F} + d_b\right) \times \sqrt{A_S} - \sqrt{A_F} \quad \text{if} \quad A_S \geq A_F \quad \text{but} \quad \sqrt{A_S} < d_b + \sqrt{A_F}$$

$$A_{B/Surr} = A_S - A_F \quad \text{if} \quad A_S > A_F \quad \text{and} \quad \sqrt{A_S} \geq d_b + \sqrt{A_F}$$

Parameter	Definition	Central Tendency	High End
$A_{B/Surr}$	Area of buffer and surrounding areas (m^2)		
d_b	Distance between source and field (side length of buffer area) (m)	300	75
A_F	Area of off-site location of interest (m^2)	Ag field = 902,450 Residential plot or home garden = 5,100	
A_S	Area of source (m^2)	Waste management of scenario-specific	

Description

This equation calculaes the area of the buffer and surrounding areas for each of the different exposure scenarios.

Table E-1.6. Scaling Factor

All Exposure Scenarios

$$SF_{0,F} = \frac{A_F}{A_S + A_{B/Surr} + A_F}$$

Parameter	Definition	Central Tendency	High End
$SF_{O,F}$	Scaling factor		
A_F	Area of off-site location of interest (m^2)	Ag. field = 902,450 Residential or home garden = 5,100	
$A_{B/Surr}$	Area of buffer and surrounding area (m^2)	Calculated (see Table E-1.5.)	
A_S	Area of source (m^2)	Waste management scenario-specific	

Description

This term is used to determine what portion of the total amount of eroded source material available for deposition within the sub-basin will be deposited onto just the off-site location of interest.

Table E-1.7. Soil Load Delivered to Off-Site Location for Material Originating from Buffer Area

All Exposure Scenarios

$$SL_{B,F} = X_{e,B} \ x \ A_B \ x \ (1 - SD_{SB}) \ x \ SF_{B,F}$$

Parameter	Definition	Central Tendency	High End
$SL_{B,F}$	Soil load delivered to off-site location for material originating from buffer area (kg/yr)		
$X_{e,B}$	Unit soil loss from buffer area (kg/m^2-sec)	Calculated (see Table E-1.8.)	
A_B	Area of buffer (m^2)	Calculated (see Table E-1.9.)	
SD_{SB}	Sediment delivery ratio for sub basin (unitless)	Calculated (see Table E-1.4.)	
$SF_{B,F}$	Scaling factor	Calculated (see Table E-1.10.)	

Description

This equation is used to calculate the load of eroded soil originating from the buffer area that is deposited onto the off-site location of interest.

Table E-1.8. Universal Soil Loss Equation (USLE) for Buffer Area

All Exposure Scenarios

$$X_{e,B} = R_B \times K_B \times LS_B \times C_B \times P_B \times \frac{907.18}{4047}$$

Parameter	Definition	Central Tendency	High End
$X_{e,B}$	Unit soil loss for buffer area (kg/m^2 -yr)		
R_B	USLE rainfall factor (1/yr)	Met Specific (See Table 2-1 of Report)	
K_B	USLE erodibility factor (ton/acre)	0.3	
LS_B	USLE length-slope factor (unitless)	1.5	
C_B	USLE cover factor (unitless)	0.1	
P_B	USLE erosion control practice factor (unitless)	1.0	
907.18	Units conversion factor (kg/ton)		
4047	Units conversion factor (m^2/acre)		

Description

This equation is used to calculate the soil loss rate from the buffer area using the Universal Soil Loss Equation; the result is used in the soil erosion load equation.

Table E-1.9. Buffer Area

All Exposure Scenarios

$$A_B = d_b \times \sqrt{A_F} \quad if \quad A_F > A_S$$

$$A_B = d_b \times \sqrt{A_S} \quad if \quad A_S \geq A_F$$

Parameter	Definition	Central Tendency	High End
A_B	Area of buffer (m^2)		
d_b	Distance between source and field (side-length of buffer area) (m)	300	75
A_F	Area of off-site location of interest (m^2)	Ag. Field = 902,450 Residential plot or home garden = 5,100	
A_S	Area of source (m^2)	Waste management scenario-specific	

Table E-1.10. Scaling Factor

All Exposure Scenarios			
$$SF_{B,F} = \frac{A_F}{A_{B/Surr} + A_F}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
$SF_{B,F}$	Scaling factor		
A_F	Area of off-site location (m^2)	Ag. field = 902,450 Residential plot or home garden = 5,100	
$A_{B/Surr}$	Area of buffer and surrounding area (m^2)	Calculated (see Table E-1.5.)	
Description			
This term is used to determine what portion of the total amount of eroded buffer material available for deposition within the sub-basin, will be deposited onto just the off-site location of interest.			

Table E-1.11. Constituent Concentration Due to Erosion in Buffer and Surrounding Areas

All Exposure Scenarios

$$C_{B/Surr} = \frac{SL_{0,B/Surr} \ x \ C_0 \ x \ ER}{ks_{B/Surr} \ x \ M_{B/Surr}} + \frac{Ds_{(1),B/Surr}}{ks_{B/Surr}}$$

Parameter	Definition	Central Tendency	High End
$C_{B/Surr}$	Constituent concentration in the buffer and surrounding area (mg/kg)		
$SL_{0,B/Surr}$	Soil load delivered to buffer and surrounding area (kg/yr)	Calculated (see Table E-1.12.)	
C_0	Source constituent concentration (mg/kg)	Chemical-specific	
$ks_{B/Surr}$	Constituent loss constant for buffer and surrounding area (1/yr)	Calculated (see Table E-1.15.)	
$M_{B/Surr}$	Mass of soil in mixing depth of buffer area (kg)	Calculated (see Table E-1.23.)	
$Ds_{(1), B/Surr}$	Deposition term for off-site field (mg/kg.yr)	Calculated (see Table E-1.14.)	
ER	Constituent enrichment ratio (unitless)	Metals = 1	

Description

This equation is used to calculate the constituent concentration in the buffer and surrounding areas as a result of erosion from the source.

Table E-1.12. Soil Load Delivered to Buffer and Surrounding Area for Material Originating from Source

All Exposure Scenarios			
$SL_{0,B/Surr} = X_{e,S} \; x \; A_S \; x \; (1 - SD_{SB}) \; x \; SF_{0,B/Surr}$			
Parameter	**Definition**	**Central Tendency**	**High End**
$SL_{0,B/Surr}$	Soil load delivered to buffer and surrounding area (kg/yr)		
$X_{e,S}$	Unit soil loss from source (kg/m^2-yr)	Calculated (see Table E-1.3.)	
A_S	Area of source (m^2)	Source-specific	
SD_{SB}	Sediment delivery ratio for sub-basin (unitless)	Calculated (see Table E-1.4.)	
$SF_{O,B/Surr}$	Scaling factor	Calculated (see Table E-1.13.)	
Description			
This equation is used to calculate the load of eroded soil originating from the source that is deposited onto the buffer and surrounding areas.			

Table E-1.13. Scaling Factor

All Exposure Scenarios

$$SF_{0,B/Surr} = \frac{A_{B/Surr}}{A_S + A_{B/Surr} + A_F}$$

Parameter	Definition	Central Tendency	High End
$SF_{0,B/surr}$	Scaling factor		
A_F	Area of off-site location (m^2)	Ag. field = 902,450 Residential plot or home garden = 5,100	
$A_{B/Surr}$	Area of buffer and surrounding area (m^2)	Calculated (see Table E-1.5.)	
A_S	Area of source (m^2)	Waste management scenario-specific	

Description

This term is used to determine what portion of the total amount of eroded source material available for deposition within the sub-basin, will be deposited onto just the buffer and surrounding areas.

Table E-1.14. Deposition Rate Factor to Buffer and Surrounding Areas

All Exposure Scenarios		
$Ds_{(1),B/Surr} = \frac{100\ x\ Q}{Z_{B/Surr}\ x\ BD}\ x\ [F_v\ (0.31536\ x\ Vdv_F\ x\ Cyv_F + Dywv_F) + (Dydp_F + Dywp_F)\ x\ (1 - F_v)]$		
Parameter	**Definition**	**Input Value**
$Ds_{(1),B/Surr}$	Deposition term for buffer and surrounding areas (mg/kg-yr)	
100	Units conversion factor ([mg-m^2]/[kg-cm^2])	
Q	Source emissions (g/sec)	Waste mgt. scenario-specific
$Z_{B/surr}$	Soil mixing depth of buffer and surrounding areas - untilled (cm)	2.5
BD	Soil bulk density (g/cm^3)	1.4
F_v	Fraction of air concentration in vapor phase (dimensionless)	Chemical-specific (see Appendix A)
0.31536	Units conversion factor (m-g-s/cm-µg-yr)	
Vdv_F	Dry deposition velocity for field (cm/s)	3
Cyv_F	Normalized vapor phase air concentration for field (µg-s/g-m^3)	Modeled
$Dywv_F$	Normalized yearly wet deposition from vapor phase for field (s/m^2-yr)	Modeled
$Dydp_F$	Normalized yearly dry deposition from particle phase for field (s/m^2-yr)	Modeled
$Dywp_F$	Normalized yearly wet deposition from particle phase for field (s/m^2-yr)	Modeled
Description		
These equations calculate average air deposition occurring over the exposure duration as a result of wet and dry deposition of particles onto soil, deposition of wet vapors to soil and diffusion of dry vapors to soil. Contaminants are assumed to be incorporated only to a finite depth (the mixing depth, Z). The air deposition rates (per unit area) for the buffer and surrounding areas are assumed to be the same as the air deposition rates (per unit area) to the field.		

Table E-1.15. Constituent Loss Constant

All Exposure Scenarios

$$ks_{B/Surr} = ksl_{B/Surr} + kse_{B/Surr} + ksr_{B/Surr} + ksg_{B/surr} + ksv_{B/Surr}$$

Parameter	Definition	Central Tendency	High End
$ks_{B/Surr}$	Constituent loss constant due to all processes for the buffer and surrounding areas (1/yr)		
$ksl_{B/Surr}$	Constituent loss constant due to leaching (1/yr)	Calculated (see Table E-1.16.)	
$kse_{B/Surr}$	Constituent loss constant due to soil erosion (1/yr)	Calculated (see Table E-1.19.)	
$ksr_{B/Surr}$	Constituent loss constant due to surface runoff (1/yr)	Calculated (see Table E-1.21.)	
ksg_{F}	Constituent loss constant due to degradation (1/yr)	NA	
$ksv_{B/Surr}$	Constituent loss constant due to volatilization (1/yr)	Calculated (see Table E-1.22.)	

Description

This equation calculates the constitutent loss constant, which accounts for the loss of constituent from soil by several mechanisms.

Table E-1.16. Constituent Loss Constant Due to Leaching

All Exposure Scenarios			
$$ksl_{B/Surr} = \frac{P + I - R - E_v}{\theta \; x \; Z_{B/Surr} \; x \; [1.0 + (BD \; x \; Kd_s / \theta)]}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
$ksl_{B/Surr}$	Constituent loss constant for buffer and surrounding area due to leaching (1/yr)		
P	Average annual precipitation (cm/yr)	Met Specific (See Table 2-1 of Report)	
I	Average annual irrigation (cm/yr)	0	
R	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
E_v	Average annual evapotranspiration (cm/yr)	Met Specific (See Table 2-1 of Report)	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
$Z_{B/Surr}$	Soil depth of buffer and surrounding area from which leaching removal occurs - untilled (cm)	2.5	
BD	Soil bulk density (g/cm^3)	1.4	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
Description			
This equation calculates the constituent loss constant due to leaching from soil.			

Table E-1.17. Soil Volumetric Water Content

All Exposure Scenarios			
$$\theta = \theta_s \left[\frac{q}{K_s}\right]^{\frac{1}{(2b+3)}}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
θ	Soil volumetric water content (mL/cm^3)		
θ_s	Soil saturated volumetric water content (mL/cm^3)	0.43	
q	Average annual recharge rate (cm/yr)	Calculated (see Table E-1.18.)	
K_s	Saturated hydraulic conductivity (cm/yr)	9110	
b	Soil-specific exponent representing water retention (unitless)	5.4	

Source: SEAM.

Table E-1.18. Average Annual Recharge

All Exposure Scenarios			
$$q = P + I - E_v - R_f$$			
Parameter	**Definition**	**Central Tendency**	**High End**
q	Average annual recharge rate (cm/yr)		
P	Average annual precipitation (cm/yr)	Met Specific (See Table 2-1 of Report)	
I	Average annual irrigation (cm/yr)	0	
E_v	Average annual evapotranspiration (cm/yr)	Met Specific (See Table 2-1 of Report)	
R_f	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	

Source: SEAM.

Table E-1.19. Constituent Loss Constant Due to Erosion

All Exposure Scenarios

$$kse_{B/Surr} \;'\; \frac{0.1 \;x\; ER \;x\; X_{e,B/Surr} \;x\; [SD_{SB} \,\%\, (1 \& SD_{SB})(\frac{A_F}{A_{B/Surr} \;\%\; A_F})]}{BD \;x\; Z_{B/Surr}} \;x\; \left(\frac{Kd_s \;x\; BD}{2\% \;(Kd_s \;x\; BD)}\right)$$

Parameter	Definition	Central Tendency	High End
$kse_{B/Surr}$	Constituent loss constant for buffer and surrounding area due to soil erosion (1/yr)	Calculated	
$X_{e,B/Surr}$	Unit soil loss for buffer and surrounding area (kg/m^2/yr)	Calculated (see Table E-1.20.)	
2	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
$Z_{B/Surr}$	Soil mixing depth for buffer and surrounding area - untilled (cm)	2.5	
BD	Soil bulk density (g/cm^3)	1.4	
Kd_s	Soil-water partition coefficient (mL/g)	Chemical-specific (see Appendix A)	
SD_{SB}	Sediment delivery ratio for the sub-basin (unitless)	Calculated (see Table E-1.4).	
ER	Constituent enrichment ratio (unitless)	Metals - 1	
A_F	Area of off-site location (m^2)	Ag. Field = 902,450 Residential plot or home garden = 5,100	
$A_{B/Surr}$	Buffer and surrounding areas (m^2)	Calculated (See Table E-1.5.)	

Table E-1.20. Universal Soil Loss Equation (USLE) for Buffer and Surrounding Areas

All Exposure Scenarios

$$X_{e,B/Surr} = R_{B/Surr} \times K_{B/Surr} \times LS_{B/Surr} \times C_{B/Surr} \times P_{B/Surr} \times \frac{907.18}{4047}$$

Parameter	Definition	Central Tendency	High End
$X_{e,B/Surr}$	Unit soil loss for buffer and surrounding area (kg/m^2 -yr)		
$R_{B/Surr}$	USLE rainfall factor (1/yr)	Met Specific (See Table 2-1 of Report)	
$K_{B/Surr}$	USLE erodibility factor (ton/acre)	0.3	
$LS_{B/Surr}$	USLE length-slope factor (unitless)	1.5	
$C_{B/Surr}$	USLE cover factor (unitless)	0.1	
$P_{B/Surr}$	USLE erosion control practice factor (unitless)	1.0	
907.18	Units conversion factor (kg/ton)		
4047	Units conversion factor (m^2/acre)		

Description

This equation is used to calculate the soil loss rate from the buffer and surrounding area using the Universal Soil Loss Equation; the result is used in the soil erosion load equation.

Table E-1.21. Constituent Loss Constant Due to Runoff

All Exposure Scenarios

$$ksr_{B/Surr} \; ' \; \frac{R}{2 \, x \, Z_{B/Surr}} \, x \left(\frac{1}{1 \% \, (Kd_s \, x \, BD / 2)} \right)$$

Parameter	Definition	Central Tendency	High End
$ksr_{B/Surr}$	Constituent loss constant for buffer and surrounding area due to runoff (1/yr)		
R	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
2	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.))	
$Z_{B/Surr}$	Soil mixing depth of buffer and surrounding area - untilled (cm)	2.5	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
BD	Soil bulk density (g/cm^3)	1.4	

Description

This equation calculates the constituent loss constant due to runoff from soil.

Table E-1.22. Constituent Loss Constant Due to Volatilization

All Exposure Scenarios

$$ksv_{B/Surr} = \left[\frac{3.1536x10^{7}\ x\ H}{Z_{B/Surr}\ x\ Kd_s\ x\ R\ x\ T\ x\ BD}\right] x \left[0.482\ x\ u^{0.78}\ x \left(\frac{\mu_a}{D_a\ x\ D_a}\right)^{-0.67} x \left(\sqrt{\frac{4\ x\ A_{B/Surr}}{B}}\right)^{-0.11}\right]$$

Parameter	Definition	Central Tendency	High End
$ksv_{B/surr}$	Constituent loss constant for buffer and surrounding area due to volatilization (1/yr)		
$3.1536x10^7$	Conversion constant (s/yr)		
H	Henry's law constant (atm-m^3/mol)	Chemical-specific (see Appendix A)	
$Z_{B/Surr}$	Soil mixing depth of buffer and surrounding area - untilled (cm)	2.5	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
R	Universal gas constant (atm-m^3/mol-K)	$8.205x10^{-5}$	
T	Ambient air temperature (K)	Met Specific (See Table 2-1 of Report)	
BD	Soil bulk density (g/cm^3)	1.4	
u	Average annual windspeed (m/s)	Met Specific (See Table 2-1 of Report)	
μ_a	Viscosity of air (g/cm-s)	$1.81x10^{-4}$	
D_a	Density of air (g/cm^3)	$1.2x10^{-3}$	
D_a	Diffusivity of constituent in air (cm^2/s)	Chemical-specific (see Appendix A)	
$A_{B/Surr}$	Surface area of buffer and surrounding area (m^2)	Calculated (see Table E-1.5.)	

Description

This equation calculates the constituent loss constant due to volatilization from soil.

Source: IEM.

Table E-1.23. Mass of Soil in Mixing Depth of Buffer and Surrounding Areas

All Exposure Scenarios			
$M_{B/Surr} = Z_{B/Surr} \ x \ A_{B/Surr} \ x \ BD \ x \ 10$			
Parameter	**Definition**	**Central Tendency**	**High End**
$M_{B/Surr}$	Mass of soil in mixing depth of buffer and surrounding area (kg)		
$Z_{B/Surr}$	Soil mixing depth for buffer and surrounding area - untilled (cm)	2.5	
$A_{B/Surr}$	Area of buffer and surrounding areas (m^2)	Calculated (see Table E-1.5.)	
BD	Soil bulk density (g/cm^3)	1.4	
10	Units conversion factor		
Description			
This equation is used to calculate the total mass of soil in the buffer and surrounding areas that will be mixing with the mass of eroded material.			

Table E-1.24. Deposition Rate Factor to Residential Plot from Source

Adult Resident Exposure Scenario

$$Ds_{(1),R} = \frac{100\ x\ Q}{Z_F\ x\ BD}\ x\ [F_v\ (0.31536\ x\ Vdv_F\ x\ Cyv_F + Dywv_F) + (Dydp_F + Dywp_F)\ x\ (1 - F_v)]$$

Parameter	Definition	Input Value
$Ds_{(1),R}$	Deposition term for residental plot - Adult Resident (mg/kg-yr)	
100	Units conversion factor ([mg-m^2]/[kg-cm^2])	
Q	Source emissions (g/m^2-s)	Waste mgt. scenario-specific
Z_F	Soil mixing depth of residential plot - untilled (cm)	2.5
BD	Soil bulk density (g/cm^3)	1.4
F_v	Fraction of air concentration in vapor phase (dimensionless)	Chemical-specific (see Appendix A)
0.31536	Units conversion factor (m-g-s/cm-µg-yr)	
Vdv_F	Dry deposition velocity for field (cm/s)	3
Cyv_F	Normalized vapor phase air concentration for field (µg-s/g-m)	Modeled
$Dywv_F$	Normalized yearly wet deposition from vapor phase for field (s/yr)	Modeled
$Dydp_F$	Normalized yearly dry deposition from particle phase for field (s/yr)	Modeled
$Dywp_F$	Normalized yearly wet deposition from particle phase for field (s/yr)	Modeled

Description

These equations calculate average air deposition occurring over the exposure duration as a result of wet and dry deposition of particles onto soil, deposition of wet vapors to soil, and diffusion of dry vapors to soil. Contaminants are assumed to be incorporated only to a finite depth (the mixing depth, Z).

Table E-1.25. Constituent Loss Constant

Adult Resident Exposure Scenario

$$ks_R = ksl_R + kse_R + ksr_R + ksg_R + ksv_R$$

Parameter	Definition	Central Tendency	High End
ks_R	Constituent loss constant due to all processes from resident plot - Adult Resident (1/yr)		
ksl_R	Constituent loss due to leaching (1/yr)	Calculated (see Table E-1.26.)	
kse_R	Constituent loss due to soil erosion (1/yr)	Calculated (see Table E-1.27.)	
ksr_R	Constituent loss due to surface runoff (1/yr)	Calculated (see Table E-1.30.)	
ksg_R	Constituent loss due to degradation (1/yr)	NA	
ksv_R	Constituent loss due to volatilization (1/yr)	Calculated (see Table E-.31..)	

Description

This equation calculates the constituent loss constant, which accounts for the loss of constituent from soil by several mechanisms.

Table E-1.26. Constituent Loss Constant Due to Leaching

Adult Resident Exposure Scenario			
$$ksl_R = \frac{P + I - R - E_v}{\theta \times Z_R \times [1.0 + (BD \times Kd_s/\theta)]}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
ksl_R	Constituent loss residential plot due to leaching - Adult Resident (1/yr)		
P	Average annual precipitation (cm/yr)	Met Specific (See Table 2-1 of Report)	
I	Average annual irrigation (cm/yr)	0	
R	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
E_v	Average annual evapotranspiration (cm/yr)	Met Specific (See Table 2-1 of Report)	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
Z_R	Soil depth for residential plot which leaching removal occurs - untilled (cm)	2.5	
BD	Soil bulk density (g/cm^3)	1.4	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
Description			
This equation calculates the constituent loss constant to leaching from soil.			

Table E-1.27. Constituent Loss Constant Due to Erosion

Adult Resident Exposure Scenario

$$kse_R \;'\; \frac{0.1 \;x\; ER \;x\; X_{e,R} \;x\; [SD_{SB} \,\%\, (1\&\,SD_{SB})(\frac{A_{BF}}{A_F \;\%\; A_{BF}})]}{BD \;x\; Z_R} \;x\; \left(\frac{Kd_s \;x\; BD}{2\% \;(Kd_s \;x\; BD)}\right)$$

Parameter	Definition	Central Tendency	High End
kse_R	Constituent loss constant due to erosion for residential plot - Adult Resident (1/yr)		
$X_{e,R}$	Unit soil loss from the residential plot (kg/m^2/yr)	Calculated (see Table E-1.28.)	
SD_{SB}	Sediment delivery ratio for sub-basin (unitless)	Calculated (see Table E-1.4.)	
ER	Contaminant enrichment ratio (unitless)	Metals = 1	
BD	Soil bulk density (g/cm^3)	1.4	
Z_F	Soil mixing depth of residential plot - untilled (cm)	2.5	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
2	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
A_F	Area of residential plot (m2)	Residential plot = 5,100	
A_{BF}	Buffer area between residential plot and waterbody (m^2)	Calculated (see Table E-1.29..)	

Description

This equation calculates the constituent loss constant due to runoff from soil.

Table E-1.28. Universal Soil Loss Equation (USLE) for Residential Plot

Adult Resident Exposure Scenario

$$X_{e,R} = R_R \times K_R \times LS_R \times C_R \times P_R \times \frac{907.18}{4047}$$

Parameter	Definition	Central Tendency	High End
$X_{e,R}$	Unit soil loss from the residential plot (kg/m^2 -yr)		
R_R	USLE rainfall factor (1/yr)	Met Specific (See Table 2-1 of Report)	
K_R	USLE erodibility factor (ton/acre)	0.3	
LS_R	USLE length-slope factor (unitless)	1.5	
C_R	USLE cover factor (unitless)	0.1	
P_R	USLE erosion control practice factor (unitless)	1.0	
907.18	Units conversion factor (kg/ton)		
4047	Units conversion factor (m^2/acre)		

Description

This equation is used to calculate the soil loss rate from the residential plot using the Universal Soil Loss Equation.

Table E-1.29. Area of Buffer Between Field and Waterbody

All Exposure Scenarios

$$A_{BF} = 0 \qquad if \quad \sqrt{A_S} \le d_b + \sqrt{A_F}$$

$$A_{BF} = \sqrt{A_F}\ x\ (\sqrt{A_S} - d_b - \sqrt{A_F}) \qquad if \ \sqrt{A_S} > d_b + \sqrt{A_F}$$

Parameter	Definition	Central Tendency	High End
A_{BF}	Area of buffer between field and waterbody (m^2)		
A_F	Area of field (m^2)	Ag. Field = 902,450 Residential plot or home garden = 5,100	
A_S	Area of source (m^2)	Waste management scenario-specific	
d_b	Distance between source and field (side-length of buffer area) (m)	300	75

Table E-1.30. Constituent Loss Constant Due to Runoff

Adult Resident Exposure Scenario			
$$ksr_R = \frac{R}{\theta \times Z_R} \times \left(\frac{1}{1 + (Kd_s \times BD/\theta)} \right)$$			
Parameter	**Definition**	**Central Tendency**	**High End**
ksr_R	Constituent loss constant due to runoff for residential plot - Adult Resident (1/yr)		
R	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
Z_R	Soil mixing depth of residential plot - untilled (cm)	2.5	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
BD	Soil bulk density (g/cm^3)	1.4	
Description			
This equation calculates the constituent loss constant due to runoff from soil.			

Table E-1.31. Constituent Loss Constant Due to Volatilization

Adult Resident Exposure Scenario

$$ksv_R = \left[\frac{3.1536x10^7 \; x \; H}{Z_R \; x \; Kd_s \; x \; R \; x \; T \; x \; BD}\right] x \left[0.482 \; x \; u^{0.78} \; x \left(\frac{\mu_a}{D_a \; x \; D_a}\right)^{-0.67} x \left(\sqrt{\frac{4 \; x \; A}{B}}\right)^{-0.11}\right]$$

Parameter	Definition	Central Tendency	High End
ksv_R	Constituent loss constant due to volatilization from residential plot - Adult Resident (1/yr)		
$3.1536x10^7$	Conversion constant (s/yr)		
H	Henry's law constant (atm-m^3/mol)	Chemical-specific (see Appendix A)	
Z_R	Soil mixing depth of residential plot - untilled (cm)	2.5	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
R	Universal gas constant (atm-m^3/mol-K)	$8.205x10^{-5}$	
T	Ambient air temperature (K)	Met Specific (See Table 2-1 of Report)	
BD	Soil bulk density (g/cm^3)	1.4	
u	Average annual windspeed (m/s)	Met Specific (See Table 2-1 of Report)	
μ_a	Viscosity of air (g/cm-s)	$1.81x10^{-4}$	
D_a	Density of air (g/cm^3)	$1.2x10^{-3}$	
D_a	Diffusivity of constituent in air (cm^2/s)	Chemical-specific (see Appendix A)	
A_F	Area of residential plot (m^2)	5,100	

Description

This equation calculates the constituent loss constant due to volatilization from soil.

Table E-1.32. Mass of Soil in Mixing Depth of Residential Plot

Adult Resident Exposure Scenario

$$M_R = Z_R \;\; x \;\; A_F \;\; x \;\; BD \;\; x \;\; 10$$

Parameter	Definition	Central Tendency	High End
M_R	Mass of soil in mixing depth of residential plot - Adult Resident (kg)		
Z_R	Soil mixing depth for residential plot - untilled (cm)	2.5	
A_F	Area of residential plot (m^2)	5,100	
BD	Soil bulk density (g/cm^3)	1.4	
10	Units conversion factor		

Description

This equation is used to calculate the total mass of soil in the residential plot that will be mixing with the mass of eroded material.

Table E-2.1. Concentration In Home Garden Due to Erosion

Home Gardener Exposure Scenario

$$C_{HG} = \frac{SL_{0,F} \ x \ C_0 \ x \ ER}{ks_{HG} \ x \ M_{HG}} + \frac{SL_{B,F} \ x \ C_{B/Surr} \ x \ ER}{ks_{HG} \ x \ M_{HG}} + \frac{Ds_{(1),HG}}{ks_{HG}}$$

Parameter	Definition	Central Tendency	High End
C_{HG}	Constituent concentration at home garden (mg/kg)		
$SL_{0,F}$	Soil load delivered to off-site location for material originating in source area (kg/yr)	Calculated (see Table E-1.2.)	
$SL_{B,F}$	Soil load delivered to off-site location for material originating in buffer area (kg/yr)	Calculated (see Table E-1.7.)	
$C_{B/Surr}$	Constituent concentration in buffer and surrounding areas (mg/kg)	Calculated (see Table E-1.11)	
$Ds_{(1),HG}$	Deposition term for the home garden (mg/kg.yr)	Calculated (see Table E-2.9.)	
C_0	Source constituent concentration (mg/kg)	Chemical-specific	
ks_{HG}	Constituent loss constant from the home garden (1/yr)	Calculated (see Table E-2.2.)	
ER	Constituent enrichment ratio (unitless)	metals = 1	
M_{HG}	Mass of soil in mixing depth of home garden (kg)	Calculated (see Table E-2.8.)	

Description

This equation is used to calculate the mass of constituent deposited onto either the home garden as a result of erosion from the source.

Table E-2.2. Constituent Loss Constant

Home Gardener Exposure Scenario

$$ks_{HG} = ksl_{HG} + kse_{HG} + ksr_{HG} + ksg_{HG} + ksv_{HG}$$

Parameter	Definition	Central Tendency	High End
ks_{HG}	Constituent soil loss constant due to all processes from home garden (1/yr)		
ksl_{HG}	Constituent loss constant due to leaching (1/yr)	Calculated (see Table E-2.3.)	
kse_{HG}	Constituent loss constant due to soil erosion (1/yr)	Calculated (see Table E-2.4)	
ksr_{HG}	Constituent loss constant due to surface runoff (1/yr)	Calculated (see Table E-2.6.)	
ksg_{HG}	Constituent loss constant due to degradation (1/yr)	NA	
ksv_{HG}	Constituent loss constant due to volatilization (1/yr)	Calculated (see Table E-2.7.)	

Description

This equation calculates the constituent loss constant, which accounts for the loss of constituent from soil by several mechanisms.

Table E-2.3. Constituent Loss Constant Due to Leaching

Home Gardener Exposure Scenario			
$$ksl_{HG} = \frac{P + I - R - E_v}{\theta \; x \; Z_{HG} \; x \; [1.0 + (BD \; x \; Kd_s / \theta)]}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
ksl_{HG}	Constituent loss constant due to leaching for home gardener (1/yr)		
P	Average annual precipitation (cm/yr)	Met Specific (See Table 2-1 of Report)	
I	Average annual irrigation (cm/yr)	0	
R	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
E_v	Average annual evapotranspiration (cm/yr)	Met Specific (See Table 2-1 of Report)	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
Z_{HG}	Soil depth of home garden from which leaching removal occurs – tilled (cm)	15	
BD	Soil bulk density (g/cm^3)	1.4	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
Description			
This equation calculates the constituent loss constant due to leaching from soil.			

Table E-2.4. Constituent Loss Constant Due to Erosion

Home Gardener Exposure Scenario			
$$kse_{HG} \; ' \; \frac{0.1 \; x \; ER \; x \; X_{e,HG} \; x \; [SD_{SB} \% \; (1 \& SD_{SB})(\frac{A_{BF}}{A_F \; \% \; A_{BF}})]}{BD \; x \; Z_{HG}} \; x \; \left(\frac{Kd_s \; x \; BD}{2 \% \; (Kd_s \; x \; BD)} \right)$$			
Parameter	**Definition**	**Central Tendency**	**High End**
kse_{HG}	Constituent loss constant due to erosion for home gardener (1/yr)		
$X_{e,HG}$	Unit soil loss from the home garden ($kg/m^2/yr$)	Calculated (see Table E-2.5.)	
SD_{SB}	Sediment delivery ratio for sub-basin (unitless)	Calculated (see Table E-1.4.)	
ER	Constituent enrichment ratio (unitless)	Metals = 1	
BD	Soil bulk density (g/cm^3)	1.4	
Z_{HG}	Soil mixing depth of home garden – tilled (cm)	15	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
2	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
A_F	Area of home garden	5,100	
A_{BF}	Buffer area between home garden and waterbody (m^2)	Calculated (see Table E-1.29.)	
Description			
This equation calculates the constituent loss constant due to runoff from soil.			

Table E-2.5. Universal Soil Loss Equation (USLE) for Home Garden

Home Gardener Exposure Scenario			
$$X_{e,HG} = RF_{HG} \times K_{HG} \times LS_{HG} \times C_{HG} \times P_{HG} \times \frac{907.18}{4047}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
$X_{e,HG}$	Unit soil loss from home garden ($kg/m^2/yr$)		
RF_{HG}	USLE rainfall factor (1/yr)	Met Specific (See Table 2-1 of Report)	
K_{HG}	USLE erodibility factor (ton/acre)	0.3	
LS_{HG}	USLE length-slope factor (unitless)	1.5	
C_{HG}	USLE cover management factor (unitless)	0.15	
P_{HG}	USLE supporting practice factor (unitless)	1	
907.18	Conversion factor (kg/ton)		
4047	Conversion factor (m^2/acre)		
Description			
This equation is used to calculate the soil loss rate from the home garden using the Universal Soil Loss Equation.			

Table E-2.6. Constituent Loss Constant Due to Runoff

Home Gardener Exposure Scenario			
$$ksr_{HG} \; ' \; \frac{R}{2 \, x \, Z_{HG}} \, x \left(\frac{1}{1 \, \% \, (Kd_s \, x \, BD/2)} \right)$$			
Parameter	**Definition**	**Central Tendency**	**High End**
ksr_F	Constituent loss constant due to runoff for home gardener (1/yr)		
R	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
2	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
Z_{HG}	Soil mixing depth of home garden – tilled (cm)	15	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
BD	Soil bulk density (g/cm^3)	1.4	
Description			
This equation calculates the constituent loss constant due to runoff from soil.			

Table E-2.7. Constituent Loss Constant Due to Volatilization

Home Gardener Exposure Scenario

$$ksv_{HG} = \left[\frac{3.1536x10^{7} \; x \; H}{Z_{HG} \; x \; Kd_{s} \; x \; R \; x \; T \; x \; BD}\right] x \left[0.482 \; x \; u^{0.78} \; x \left(\frac{\mu_{a}}{D_{a} \; x \; D_{a}}\right)^{-0.67} x \left(\sqrt{\frac{4 \; x \; A_{F}}{B}}\right)^{-0.11}\right]$$

Parameter	Definition	Central Tendency	High End
ksv_{HG}	Constituent loss constant due to volatilization for home gardener (1/yr)		
$3.1536x10^{7}$	Conversion constant (s/yr)		
H	Henry's law constant (atm-m^3/mol)	Chemical-specific (see Appendix A)	
Z_{HG}	Soil mixing depth of home garden – tilled (cm)	15	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
R	Universal gas constant (atm-m^3/mol-K)	$8.205x10^{-5}$	
T	Ambient air temperature (K)	Met Specific (See Table 2-1 of Report)	
BD	Soil bulk density (g/cm^3)	1.4	
u	Average annual windspeed (m/s)	Met Specific (See Table 2-1 of Report)	
μ_a	Viscosity of air (g/cm-s)	$1.81x10^{-4}$	
D_a	Density of air (g/cm^3)	$1.2x10^{-3}$	
D_a	Diffusivity of constituent in air (cm^2/s)	Chemical-specific (see Appendix A)	
A_F	Area of home garden (m^2)	5,100	

Description

This equation calculates the constituent loss constant due to volatilization from soil.

Table E-2.8. Mass of Soil in Mixing Depth of Home Garden

Home Gardener Exposure Scenario			
$M_{HG} = Z_{HG} \; x \; A_F \; x \; BD \; x \; 10$			
Parameter	**Definition**	**Central Tendency**	**High End**
M_{HG}	Mass of soil in mixing depth of home garden (kg)		
Z_{HG}	Soil mixing depth for home garden – tilled (cm)	15	
A_F	Area of home garden (m^2)	5,100	
BD	Soil bulk density (g/cm^3)	1.4	
10	Units conversion factor		
Description			
This equation is used to calculate the total mass of soil in the home garden that will be mixing with the mass of eroded material.			

Table E-2.9. Deposition Rate Factor to Home Garden from Source

Home Gardener Exposure Scenario

$$Ds_{(1),HG} = \frac{100 \; x \; Q}{Z_{HG} \; x \; BD} \; x \; [F_v \, (0.31536 \; x \; Vdv_{HG} \; x \; Cyv_{HG} + Dywv_{HG}) + (Dydp_{HG} + Dywp_{HG}) \; x \; (1 - F_v)]$$

Parameter	Definition	Input Value
$Ds_{(1),HG}$	Deposition term for home garden (mg/kg-yr)	
100	Units conversion factor ([mg-m^2]/[kg-cm^2])	
Q	Source emissions (g/sec)	Waste mgt. scenario-specific
Z_{HG}	Soil mixing depth of home garden – tilled (cm)	15
BD	Soil bulk density (g/cm^3)	1.4
F_v	Fraction of air concentration in vapor phase (dimensionless)	Chemical-specific (see Appendix A)
0.31536	Units conversion factor (m-g-s/cm-µg-yr)	
Vdv_{HG}	Dry deposition velocity for home garden (cm/s)	3
Cyv_{HG}	Normalized vapor phase air concentration for home garden (µg-s/g-m^3)	Modeled
$Dywv_{HG}$	Normalized yearly wet deposition from vapor phase for home garden (s/m^2-yr)	Modeled
$Dydp_{HG}$	Normalized yearly dry deposition from particle phase for home garden (s/m^2-yr)	Modeled
$Dywp_{HG}$	Normalized yearly wet deposition from particle phase for home garden (s/m^2-yr)	Modeled

Description

These equations calculate average air deposition occurring over the exposure duration as a result of wet and dry deposition of particles onto soil, deposition of wet vapors to soil, and diffusion of dry vapors to soil. Constituents are assumed to be incorporated only to a finite depth (the mixing depth, Z).

Table E-2.10. Aboveground Produce Concentration Due to Direct Deposition

Home Gardener Scenario

$$Pd_{HG} = \frac{1000 \ x \ Q \ x \ (1 - F_v) \ x \ [Dydp_{HG} + (Fw \ x \ Dywp_{HG})] \ x \ Rp \ x \ [(1.0 - \exp(-kp \ x \ Tp)]}{Yp \ x \ kp}$$

Parameter	Definition	Central Tendency	High End
Pd_{HG}	Concentration in plant due to direct deposition (mg/kg) - Home Gardener		
1000	Units conversion factor (mg/g)		
Q	Emissions (g)	Waste mgt. scenario-specific	
F_v	Fraction of air concentration in vapor phase (dimensionless)	Chemical-specific (see Appendix A)	
$Dydp_{HG}$	Normalized yearly dry deposition from particle phase (s/m^2-yr)	Modeled	
Fw	Fraction of wet deposition that adheres to plant (dimensionless)	Chemical-specific (see Appendix A)	
$Dywp_{HG}$	Yearly particle phase wet deposition rate ($g/m^2/yr$)	Modeled	
Rp	Interception fraction of edible portion of plant (dimensionless) - aboveground vegetable - forage	 0.3 0.5	
kp	Plant surface loss coefficient (1/yr)	18	
Tp	Length of plant exposure to deposition of edible portion of plant, per harvest (yrs) - grain, root vegetable and aboveground vegetable - forage	 0.16 0.12	
Yp	Yield or standing crop biomass of the edible portion of the plant (kg DW/m^2) - aboveground vegetable - forage	 3 0.24	

Description

This equation calculates the constituent concentration in aboveground vegetation due to wet and dry deposition of constituent on the plant surface.

Table E-2.11. Aboveground Produce Concentration Due to Air-to-Plant Transfer

Home Gardener Scenario		
$$Pv_{HG} = Q \times F_v \times \frac{Cyv_{HG} \times Bv \times VG_{ag}}{D_a}$$		
Parameter	**Definition**	**Input Value**
Pv_{HG}	Concentration of constituent in the plant due to air-to-plant transfer (mg/kg) - Home Gardener	
Q	Emissions (g)	Waste mgt. scenario-specific
F_v	Fraction of air concentration in vapor phase (dimensionless)	Chemical-specific (see Appendix A)
Cyv_{HG}	Normalized vapor phase air concentration (µg-sec/g-m^3)	Modeled (see Appendix D)
Bv	Air-to-plant biotransfer factor ([mg constituent/kg plant tissue DW]/[µg constituent/g air])	Chemical-specific (see Appendix A)
VG_{ag}	Empirical correction factor for above-ground produce (dimensionless)	0.01
D_a	Density of air (g/cm^3)	1.2 x 10^{-3}
Description		
This equation calculates the constituent concentration in aboveground vegetation due to direct uptake of vapor phase chemicals into the plant leaves.		

Table E-2.12. Aboveground Produce Concentration Due to Root Uptake

Home Gardener Scenario

$$Pr_{HG} = C_{HG} \times Br$$

Parameter	Definition	Central Tendency	High End
Pr_{HG}	Concentration of constituent in the plant due to direct uptake from soil (mg/kg) - Home Gardener		
C_{HG}	Average soil concentration of constituent over exposure duration (mg/kg)	Calculated (see Table E-2.1.)	
Br	Plant-soil bioconcentration factor for aboveground produce [µg/g DW]/[µg/g soil]	Chemical-specific (see Appendix A)	

Description

This equation calculates the constituent concentration in aboveground vegetation due to direct uptake of chemicals from soil.

Table E-2.13. Root Vegetable Concentration Due to Root Uptake

Home Gardener Scenario			
$$Pr_{bg,HG} = \frac{C_{HG}\ x\ RCF}{Kd_s}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
$Pr_{bg,\ HG}$	Concentration of constituent in belowground plant parts due to root uptake (mg/kg) - Home Gardener		
C_{HG}	Soil concentration of constituent (mg/kg)	Calculated (see Table E-2.1.)	
RCF	Ratio of concentration in roots to concentration in soil pore water ([mg constituent/kg plant tissue FW] / [Fg constituent/mL pore water])	Chemical-specific (see Appendix A)	
Kd_s	Soil-water partition coefficient (mL/g)	Chemical-specific (see Appendix A)	
Description			
This equation calculates the constituent concentration in root vegetables due to uptake from the soil water.			

Table E-3.1. Constituent Concentration In Agricultural Field Due to Erosion

Farmer Exposure Scenario

$$C_{SF} = \frac{SL_{0,F} \ x \ C_0 \ x \ ER}{ks_{SF} \ x \ M_{SF}} + \frac{SL_{B,F} \ x \ C_{B/Surr} \ x \ ER}{ks_{SF} \ x \ M_{SF}} + \frac{Ds_{(1),SF}}{ks_{SF}}$$

Parameter	Definition	Central Tendency	High End
C_{SF}	Constituent concentration in agricultural field (mg/kg)		
$SL_{0,F}$	Soil load delivered to off-site location for material originating in source area (kg/yr)	Calculated (see Table E-1.2.)	
$SL_{B,F}$	Soil load delivered to off-site location for material originating in buffer area (kg/yr)	Calculated (see Table E-1.7.)	
$C_{B/Surr}$	Constituent concentration in buffer and surrounding areas (mg/kg)	Calculated (see Table E-1.11.)	
$Ds_{(1),SF}$	Deposition term for the agricultural field (mg/kg.yr)	Calculated (see Table E-3.9.)	
C_0	Source constituent concentration (mg/kg)	Chemical-specific	
ks_{SF}	Constituent loss constant from the agricultural field (1/yr)	Calculated (see Table E-3.2.)	
M_{SF}	Mass of soil in mixing depth of agricultural field (kg)	Calculated (see Table E-3.8.)	
ER	Constituent enrichment ratio (unitless)	metals = 1	

Description

This equation is used to calculate the mass of constituent deposited onto the agricultural field as a result of erosion from the source.

Table E-3.2. Soil Loss Constant

Farmer Exposure Scenario

$$ks_{SF} = ksl_{SF} + kse_{SF} + ksr_{SF} + ksg_{SF} + ksv_{SF}$$

Parameter	Definition	Central Tendency	High End
ks_{SF}	Constituent soil loss constant due to all processes from agricultural field (1/yr)		
ksl_{SF}	Constituent loss constant due to leaching (1/yr)	Calculated (see Table E-3.3.)	
kse_{SF}	Constituent loss constant due to soil erosion (1/yr)	Calculated (see Table E-3.4)	
ksr_{SF}	Constituent loss constant due to surface runoff (1/yr)	Calculated (see Table E-3.6.)	
ksg_{SF}	Constituent loss constant due to degradation (1/yr)	NA	
ksv_{SF}	Constituent loss constant due to volatilization (1/yr)	Calculated (see Table E-3.7.)	

Description

This equation calculates the constituent loss constant, which accounts for the loss of constituent from soil by several mechanisms.

Table E-3.3. Loss Constant due to Leaching

Farmer Exposure Scenario

$$ksl_{SF} = \frac{P + I - R - E_v}{\theta \; x \; Z_{SF} \; x \; [1.0 + (BD \; x \; Kd_s / \theta)]}$$

Parameter	Definition	Central Tendency	High End
ksl_{SF}	Constituent loss constant due to leaching for agricultural field (1/yr)		
P	Average annual precipitation (cm/yr)	Met Specific (See Table 2-1 of Report)	
I	Average annual irrigation (cm/yr)	0	
R	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
E_v	Average annual evapotranspiration (cm/yr)	Met Specific (See Table 2-1 of Report)	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
Z_{SF}	Soil depth of agricultural field from which leaching removal occurs – tilled (cm)	15	
BD	Soil bulk density (g/cm^3)	1.4	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	

Description

This equation calculates the constituent loss constant due to leaching from soil.

Table E-3.4. Constituent Loss Constant Due to Erosion

Farmer Exposure Scenario			
$$kse_{SF} = \frac{0.1 \times ER \times X_{e,SF} \times [SD_{SB} + (1 - SD_{SB})(\frac{A_{BF}}{A_F + A_{BF}})]}{BD \times Z_{SF}} \times \left(\frac{Kd_s \times BD}{\theta + (Kd_s \times BD)}\right)$$			
Parameter	**Definition**	**Central Tendency**	**High End**
kse_{SF}	Constituent loss constant due to erosion for agricultural field (1/yr)		
$X_{e,SF}$	Unit soil loss from the agricultural field (kg/m^2/yr)	Calculated (see Table E-3.5.)	
SD_{SB}	Sediment delivery ratio for sub-basin (unitless)	Calculated (see Table E-1.4.)	
ER	Constituent enrichment ratio (unitless)	Metals = 1	
BD	Soil bulk density (g/cm^3)	1.4	
Z_{SF}	Soil mixing depth of agricultural field– tilled (cm)	15	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
A_F	Area of agricultural field (m^2)	902,450	
A_{BF}	Buffer area between agricultural field and waterbody (m^2)	Calculated (see Table E-1.29.)	
Description			
This equation calculates the constituent loss constant due to runoff from soil.			

Table E-3.5. Universal Soil Loss Equation (USLE) for Agricultural Field

Farmer Exposure Scenario			
$$X_{e,SF} = RF_{SF} \times K_{SF} \times LS_{SF} \times C_{SF} \times P_{SF} \times \frac{907.18}{4047}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
$X_{e,SF}$	Unit soil loss from the agricultural field ($kg/m^2/yr$)		
RF_{SF}	USLE rainfall factor (1/yr)	Met Specific (See Table 2-1 of Report)	
K_{SF}	USLE erodibility factor (ton/acre)	0.3	
LS_{SF}	USLE length-slope factor (unitless)	1.5	
C_{SF}	USLE cover management factor (unitless)	0.15	
P_{SF}	USLE supporting practice factor (unitless)	1	
907.18	Conversion factor (kg/ton)		
4047	Conversion factor (m^2/acre)		
Description			
This equation is used to calculate the soil loss rate from the agricultural field using the Universal Soil Loss Equation.			

Table E-3.6. Constituent Loss Constant Due to Runoff

Farmer Exposure Scenario

$$ksr_{SF} = \frac{R}{\theta \times Z_{SF}} \times \left(\frac{1}{1 + (Kd_s \times BD/\theta)} \right)$$

Parameter	Definition	Central Tendency	High End
ksr_{SF}	Constituent loss constant due to runoff from agricultural field (1/yr)		
R	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
Z_{SF}	Soil mixing depth of agricultural field–tilled (cm)	15	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
BD	Soil bulk density (g/cm^3)	1.4	

Description

This equation calculates the constituent loss constant due to runoff from soil.

Table E-3.7. Constituent Loss Constant Due to Volatilization

Farmer Exposure Scenario

$$ksv_{SF} = \left[\frac{3.1536x10^{7}\ x\ H}{Z_{SF}\ x\ Kd_{s}\ x\ R\ x\ T\ x\ BD}\right] x \left[0.482\ x\ u^{0.78}\ x \left(\frac{\mu_a}{\rho_a\ x\ D_a}\right)^{-0.67} x \left(\sqrt{\frac{4\ x\ A_F}{\pi}}\right)^{-0.11}\right]$$

Parameter	Definition	Central Tendency	High End
ksv_{SF}	Constituent loss constant due to volatilization for agricultural field (1/yr)		
$3.1536x10^7$	Conversion constant (s/yr)		
H	Henry's law constant (atm-m^3/mol)	Chemical-specific (see Appendix A)	
Z_{SF}	Soil mixing depth of agricultural field (cm)	15	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
R	Universal gas constant (atm-m^3/mol-K)	$8.205x10^{-5}$	
T	Ambient air temperature (K)	Met Specific (See Table 2-1 of Report)	
BD	Soil bulk density (g/cm^3)	1.4	
u	Average annual windspeed (m/s)	Met Specific (See Table 2-1 of Report)	
μ_a	Viscosity of air (g/cm-s)	$1.81x10^{-4}$	
ρ_a	Density of air (g/cm^3)	$1.2x10^{-3}$	
D_a	Diffusivity of constituent in air (cm^2/s)	Chemical-specific (see Appendix A)	
A_F	Area of agricultural field (m^2)	902,450	

Description

This equation calculates the constituent loss constant due to volatilization from soil.

Table E-3.8. Mass of Soil in Mixing Depth of Agricultural Field

Farmer Exposure Scenario

$$M_{SF} = Z_{SF} \ x \ A_F \ x \ BD \ x \ 10$$

Parameter	Definition	Central Tendency	High End
M_{SF}	Mass of soil in mixing depth of agricultural field (kg)		
Z_{SF}	Soil mixing depth for agricultural field – tilled (cm)	15	
A_F	Area of agricultural field (m^2)	902,450	
BD	Soil bulk density (g/cm^3)	1.4	
10	Units conversion factor		

Description

This equation is used to calculate the total mass of soil in the agricultural field that will be mixing with the mass of eroded material.

Table E-3.9. Deposition Rate Factor to Agricultural Field from Source

Farmer Exposure Scenario

$$Ds_{(1),SF} = \frac{100\ x\ Q}{Z_{SF}\ x\ BD}\ x\ [F_v\ (0.31536\ x\ Vdv_{SF}\ x\ Cyv_{SF} + Dywv_{SF}) + (Dydp_{SF} + Dywp_{SF})\ x\ (1 - F_v)]$$

Parameter	Definition	Input Value
$Ds_{(1),SF}$	Deposition term for agricultural field (mg/kg-yr)	
100	Units conversion factor ([mg-m^2]/[kg-cm^2])	
Q	Source emissions (g/sec)	Waste mgt. scenario-specific
Z_{SF}	Soil mixing depth of agricultural field (cm)	15
BD	Soil bulk density (g/cm^3)	1.4
F_v	Fraction of air concentration in vapor phase (dimensionless)	Chemical-specific (see Appendix A)
0.31536	Units conversion factor (m-g-s/cm-µg-yr)	
Vdv_{SF}	Dry deposition velocity for agricultural field (cm/s)	3
Cyv_{SF}	Normalized vapor phase air concentration for agricultural field (µg-s/g-m^3)	Modeled
$Dywv_{SF}$	Normalized yearly wet deposition from vapor phase for agricultural field (s/m^2-yr)	Modeled
$Dydp_{SF}$	Normalized yearly dry deposition from particle phase for agricultural field (s/m^2-yr)	Modeled
$Dywp_{SF}$	Normalized yearly wet deposition from particle phase for agricultural field (s/m^2-yr)	Modeled

Description

These equations calculate average air deposition occurring over the exposure duration as a result of wet and dry deposition of particles onto soil, deposition of wet vapors to soil, and diffusion of dry vapors to soil. Constituents are assumed to be incorporated only to a finite depth (the mixing depth, Z).

Table E-3.10. Aboveground Produce Concentration Due to Direct Deposition

Farmer Exposure Scenario

$$Pd_{SF} = \frac{1000 \ x \ Q \ x \ (1 - F_v) \ x \ [Dydp_{SF} + (Fw \ x \ Dywp_{SF})] \ x \ Rp \ x \ [(1.0 - \exp(-kp \ x \ Tp))]}{Yp \ x \ kp}$$

Parameter	Definition	Central Tendency	High End
Pd_{SF}	Concentration in plant due to direct deposition (mg/kg) - Farmer		
1000	Units conversion factor (mg/g)		
Q	Emissions (g)	Waste mgt. scenario-specific	
F_v	Fraction of air concentration in vapor phase (dimensionless)	Chemical-specific (see Appendix A)	
$Dydp_{SF}$	Normalized yearly dry deposition from particle phase (s/m^2-yr)	Modeled	
Fw	Fraction of wet deposition that adheres to plant (dimensionless)	Chemical-specific (see Appendix A)	
$Dywp_{SF}$	Yearly particle phase wet deposition rate (g/m^2/yr)	Modeled	
Rp	Interception fraction of edible portion of plant (dimensionless) - aboveground vegetable - forage	 0.04 0.5	
kp	Plant surface loss coefficient (1/yr)	18	
Tp	Length of plant exposure to deposition of edible portion of plant, per harvest (yrs) - grain, root vegetable and aboveground vegetable - forage	 0.16 0.12	
Yp	Yield or standing crop biomass of the edible portion of the plant (kg DW/m^2) - aboveground vegetable - forage	 3 0.24	

Description

This equation calculates the constituent concentration in aboveground vegetation due to wet and dry deposition of constituent on the plant surface.

Table E-3.11. Aboveground Produce Concentration Due to Air-to-Plant Transfer

Farmer Exposure Scenario		
$$Pv_{SF} = Q \ x \ F_v \ x \ \frac{Cyv_{SF} \ x \ Bv \ x \ VG_{ag}}{D_a}$$		
Parameter	**Definition**	**Input Value**
Pv_{SF}	Concentration of constituent in the plant due to air-to-plant transfer (mg/kg) - Farmer	
Q	Emissions (g)	Waste mgt. scenario-specific
F_v	Fraction of air concentration in vapor phase (dimensionless)	Chemical-specific (see Appendix A)
Cyv_{SF}	Normalized vapor phase air concentration (µg-sec/g-m^3)	Modeled
Bv	Air-to-plant biotransfer factor ([mg constituent/kg plant tissue DW]/[µg constituent/g air])	Chemical-specific (see Appendix A)
VG_{ag}	Empirical correction factor for above-ground produce (dimensionless)	0.01
D_a	Density of air (g/cm^3)	1.2×10^{-3}
Description		
This equation calculates the constituent concentration in aboveground vegetation due to direct uptake of vapor phase chemical into the plant leaves.		

Table E-3.12. Aboveground Produce Concentration Due to Root Uptake

Farmer Exposure Scenario			
$$Pr_{SF} = C_{SF} \times Br$$			
Parameter	**Definition**	**Central Tendency**	**High End**
Pr_{SF}	Concentration of constituent in the plant due to direct uptake from soil (mg/kg) - Farmer		
C_{SF}	Average soil concentration of constituent over exposure duration (mg/kg)	Calculated (see Table E-3.1.)	
Br	Plant-soil bioconcentration factor for aboveground produce [µg/g DW]/[µg/g soil]	Chemical-specific (see Appendix A)	
Description			
This equation calculates the constituent concentration in aboveground vegetation due to direct uptake of chemicals from soil.			

Table E-3.13. Root Vegetable Concentration Due to Root Uptake

Farmer Exposure Scenario

$$Pr_{bg,SF} = \frac{C_{SF} \ x \ RCF}{Kd_s}$$

Parameter	Definition	Central Tendency	High End
$Pr_{bg,\ SF}$	Concentration of constituent in belowground plant parts due to root uptake (mg/kg) - Farmer		
C_{SF}	Soil concentration of constituent (mg/kg)	Calculated (see Table E-3.1.)	
RCF	Ratio of concentration in roots to concentration in soil pore water ([mg constituent/kg plant tissue FW] / [Fg constituent/mL pore water])	Chemical-specific (see Appendix A)	
Kd_s	Soil-water partition coefficient (mL/g)	Chemical-specific (see Appendix A)	

Description

This equation calculates the constituent concentration in root vegetables due to uptake from the soil water.

Table E-3.14. Beef Concentration Due to Plant and Soil Ingestion

Farmer Scenario

$$A_{beef} = (F \times Qp \times P + Qs \times C_{SF}) \times Ba_{beef}$$

Parameter	Definition	Central Tendency	High End
A_{beef}	Concentration of constituent in beef (mg/kg)		
F	Fraction of plant grown on contaminated soil and eaten by the animal grain or forage (dimensionless)	1	
Qp	Quantity of plant eaten by the animal each day (kg plant tissue DW/day) - beef cattle–grain - beef cattle–forage	 0.47 8.8	
P	Total concentration of constituent in the plant eaten by the animal (mg/kg) = Pd + Pv + Pr	Calculated (see Tables E-3.16, E-3.17, E-3.18)	
Qs	Quantity of soil eaten by the foraging animal (kg soil/day)	0.5	
C_{SF}	Soil concentration (mg/kg)	Calculated (see Table E-3.1)	
Ba_{beef}	Biotransfer factor for beef (d/kg)	Chemical-specific (see Appendix A)	

Description

This equation calculates the concentration of constituent in beef from ingestion of forage and soil.

Table E-3.15. Milk Concentration Due to Plant and Soil Ingestion

Farmer Scenario

$$A_{milk} = (F \times Qp \times P + Qs \times C_{SF}) \times Ba_{milk}$$

Parameter	Definition	Central Tendency	High End
A_{milk}	Concentration of constituent in milk (mg/kg)		
F	Fraction of plant grown on contaminated soil and eaten by the animal grain or forage (dimensionless)	1	
Qp	Quantity of plant eaten by the animal each day (kg plant tissue DW/day) - dairy cattle–grain - dairy cattle–forage	 3 13.2	
P	Total concentration of constituent in the plant eaten by the animal (mg/kg) = Pd + Pv + Pr	Calculated (see Tables E-3.16., E-3.17., E-3.18.)	
Qs	Quantity of soil eaten by the foraging animal (kg soil/day)	0.4	
C_{SF}	Soil concentration (mg/kg)	Calculated (see Table E-3.1.)	
Ba_{milk}	Biotransfer factor for milk (day/kg)	Chemical-specific (see Appendix A)	

Description

This equation calculates the concentration of constituent in milk from ingestion of forage and soil.

Table E-3.16. Forage (Pasture Grass/Hay) Concentration Due to Direct Deposition

Farmer Scenario

$$Pd = \frac{1000 \; x \; Q \; x \; (1 - F_v)[Dydp_{SF} + (Fw \; x \; Dywp_{SF})] \; x \; Rp \; x \; [(1.0 - \exp(-kp \; x \; Tp))]}{Yp \; x \; kp}$$

Parameter	Definition	Central Tendency	High End
Pd	Concentration in plant due to direct deposition (mg/kg)		
1000	Units conversion factor (mg/g)		
Q	Emissions (g/s)	Waste mgt. scenario-specific	
F_v	Fraction of constituent air concentration present in the vapor phase (dimensionless)	Modeled	
$Dydp_{SF}$	Normalized yearly dry deposition from particle phase (s/m^2-yr)	Modeled	
Fw	Fraction of wet deposition that adheres to plant surfaces (dimensionless)	Chemical-specific (see Appendix A)	
$Dywp_{SF}$	Yearly particle phase wet deposition rate ($g/m^2/yr$)	Modeled	
Rp	Interception fraction of edible portion of plant (dimensionless) - aboveground vegetable - forage	 0.04 0.5	
kp	Plant surface loss coefficient (1/yr)	18	
Tp	Length of the plant exposure to deposition of edible portion of plant per harvest (yrs) - grain, root vegetable and aboveground vegetable - forage	 0.16 0.12	
Yp	Yield or standing crop biomass of the edible portion of the plant (kg DW/m^2) - above-ground vegetable - forage	 3 0.24	

Description

This equation calculates the constituent concentration in aboveground vegetation due to wet and dry deposition of constituent on the plant surface.

Table E-3.17. Forage (Pasture Grass/Hay) Concentration Due to Air-to-Plant Transfer

Farmer Scenario

$$Pv = \frac{Cyv_{SF} \; x \; Bv \; x \; VG_{ag}}{\rho_a}$$

Parameter	Definition	Central Tendency	High End
Pv	Concentration of constituent in the plant due to air-to-plant transfer (mg/kg)		
Cyv_{SF}	Vapor phase air concentration of constituent in air due to direct emissions (µg constituent/m^3)	Modeled	
Bv	Air-to-plant biotransfer factor ([mg constituent/kg plant tissue DW]/[µg [constituent/g air])	Chemical-specific (see Appendix A)	
VG_{ag}	Empirical correction factor that reduces produce concentration because Bv was developed for azalea leaves.	1.0	
ρ_a	Density of air (g/cm^3)	1.2×10^{-3}	

Description

This equation calculates the constituent concentration in aboveground vegetation due to direct uptake of vapor phase chemicals into the plant leaves.

Table E-3.18. Forage/Silage/Grain Concentration Due to Root Uptake

Farmer Scenario

$$Pr = \sum_i C_{SF} \times Br_i$$

Parameter	Definition	Input Value
Pr	Concentration of constituent in the plant due to direct uptake from soil (mg/kg)	
C_{SF}	Average soil concentration of constituent over exposure duration (mg/kg)	Calculated (see Table E-3.1.)
Br_i	Plant-soil bioconcentration factor plant species i (forage/silage/grain) [μg/g DW]/[μg/g soil]	Chemical-specific (see Appendix A)

Description

This equation calculates the constituent concentration in aboveground vegetation due to direct uptake of constituents from soil.

Table E-4.1. Watershed Constituent Concentration

All Exposure Scenarios

$$C_{WS} = \frac{Ds_{(1)WS}}{ks_{ws}}$$

Parameter	Definition	Central Tendency	High End
C_{WS}	Constituent concentration in watershed area outside of sub-basin (mg/kg)		
$Ds_{(1),WS}$	Deposition term for the watershed (mg/kg-yr)	Calculated (see Table E-4.2.)	
ks_{WS}	Constituent loss constant from the watershed (1/yr)	Calculated (see Table E-4.3.)	

Description

This equation is used to calculate the mass of constituent deposited onto the watershed area outside of sub-basin as a result of air deposition.

Table E-4.2. Deposition Rate Factor to Watershed from Source

All Exposure Scenarios

$$Ds_{(1)WS} = \frac{100\,x\,Q}{Z_{WS}\,x\,BD}\,[F_v\,(Vdv_{WS}\ x\ Cyv_{WS}\ x\ 10^{-6}) + (Dydp_{WS} + Dywp_{WS})\ x\ (1 - F_v)]$$

Parameter	Definition	Central Tendency	High End
$Ds_{(1)WS}$	Deposition rate factor for the watershed (mg/kg-yr)		
100	Units conversion factor ([mg-m^2]/[kg-cm^2])		
Q	Source emissions (g/m^2-s)	Waste management scenario specific	
Z_{WS}	Soil mixing depth in general watershed area (cm)	2.5	
BD	Soil bulk density (g/cm^3)	1.4	
F_v	Fraction of air concentration in vapor phase (dimensionless)	Chemical specific (see Appendix A)	
10^{-6}	Units conversion factor (g/µg)		
Vdv_{WS}	Gas phase mass transfer to soil (m/yr)	31,500	
Cyv_{WS}	Normalized vapor phase air concentration for watershed (µg-s/m-g)	Modeled	
$Dywv_{WS}$	Normalized yearly wet deposition from vapor phase for watershed (s/yr)	Modeled	
$Dydp_{WS}$	Normalized yearly dry deposition from particle phase for watershed (s/yr)	Modeled	
$Dywp_{WS}$	Normalized yearly wet deposition from particle phase for watershed (s/yr)	Modeled	

Description

These equations calculate average air deposition occurring over the exposure duration as a result of wet and dry deposition of particles onto soil, deposition of wet vapors to soil, and diffusion of dry vapors to soil. Constituents are assumed to be incorporated only to a finite depth (the mixing depth, Z).

Table E-4.3. Constituent Loss Constant

All Exposure Scenarios

$$ks_{ws} = ksl_{ws} + kse_{ws} + ksr_{ws} + ksg_{ws} + ksv_{ws}$$

Parameter	Definition	Central Tendency	High End
ks_{ws}	Constituent loss constant due to all processes from watershed (1/yr)		
ksl_{ws}	Constituent loss constant for watershed due to leaching (1/yr)	Calculated (see Table E-4.4.)	
kse_{ws}	Constituent loss constant for watershed due to soil erosion (1/yr)	Calculated (see Table E-4.5.)	
ksr_{ws}	Constituent loss constant for watershed due to surface runoff (1/yr)	Calculated (see Table E-4.8.)	
ksg_{ws}	Constituent loss constant for watershed due to degradation (1/yr)	NA	
ksv_{ws}	Constituent constant for watershed due to volatilization (1/yr)	Calculated (see Table E-4.9.)	

Description

This equation calculates the constituent loss constant, which accounts for the loss of constituent from soil by several mechanisms.

Table E-4.4. Constituent Loss Constant due to Leaching

All Exposure Scenarios

$$ksl_{WS} = \frac{P + I - R - E_v}{\theta \; x \; Z_{WS} \; x \; [1.0 + (BD \; x \; Kd_s / \theta)]}$$

Parameter	Definition	Central Tendency	High End
$ksl_{,WS}$	Constituent loss constant for watershed due to leaching (1/yr)		
P	Average annual precipitation (cm/yr)	Met Specific (See Table 2-1 of Report)	
I	Average annual irrigation (cm/yr)	0	
R	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
E_v	Average annual evapotranspiration (cm/yr)	Met Specific (See Table 2-1 of Report)	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
Z_{WS}	Soil depth for watershed from which leaching removal occurs – untilled (cm)	2.5	
BD	Soil bulk density (g/cm^3)	1.4	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical specific (see Appendix A)	

Description

This equation calculates the constituent loss constant due to leaching from soil.

Table E-4.5. Constituent Loss Constant Due to Erosion

All Exposure Scenarios			
$kse_{WS} \ ' \ \frac{0.1 \ x \ X_{e,WS} \ x \ SD_{WS} \ x \ ER}{BD \ x \ Z_{WS}} \ x \ \left(\frac{Kd_s \ x \ BD}{2\% \ (Kd_s \ x \ BD)} \right)$			
Parameter	**Definition**	**Central Tendency**	**High End**
kse_{WS}	Constituent loss constant due to erosion for watershed (1/yr)		
$X_{e,WS}$	Unit soil loss for watershed (kg/m^2/yr)	Calculated (see Table E-4.6.)	
SD_{WS}	Sediment delivery ratio for watershed (unitless)	Calculated (see Table E-4.7.)	
ER	Constituent enrichment ratio (unitless)	Metals = 1	
BD	Soil bulk density (g/cm^3)	1.4	
Z_{WS}	Soil mixing depth in watershed – untilled (cm)	2.5	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical specific (see Appendix A)	
2	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
0.1	Units conversion factor (g-m^2)/(kg-cm^2)		
Description			
This equation calculates the constituent loss constant due to runoff from soil.			

Table E-4.6. Universal Soil Loss Equation (USLE) for the Watershed

All Exposure Scenarios

$$X_{e,WS} = R_{WS} \times K_{WS} \times LS_{WS} \times C_{WS} \times P_{WS} \times \frac{907.18}{4{,}047}$$

Parameter	Definition	Central Tendency	High End
$X_{e,WS}$	Unit soil loss from the watershed (kg/m^2 -yr)		
R_{WS}	USLE rainfall factor (1/yr)	Met Specific (See Table 2-1 of Report)	
K_{WS}	USLE erodibility factor (ton/acre)	0.3	
LS_{WS}	USLE length-slope factor (unitless)	1.5	
C_{WS}	USLE cover factor (unitless)	0.1	
P_{WS}	USLE erosion control practice factor (unitless)	1.0	
907.18	Units conversion factor (kg/ton)		
4,047	Units conversion factor (m^2/acre)		

Description

This equation is used to calculate the soil loss rate from the watershed using the Universal Soil Loss Equation.

Table E-4.7. Sediment Delivery Ratio

Fisher Scenario			
$$SD_{WS} = a \times (A_{WS})^{-b}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
SD_{WS}	Sediment delivery ratio for watershed (unitless)		
a	Empirical intercept coefficient	Depends on watershed area; see table below	
A_{WS}	Watershed area receiving fallout (m^2)	2.93×10^9	
b	Empirical slope coefficient	0.125	
Description			
This equation calculates the sediment delivery ratio for the watershed.			

Values for Empirical Intercept Coefficient, a

Watershed area (sq. miles)	"a" coefficient (unitless)
≤ 0.1	2.1
1	1.9
10	1.4
100	1.2
1,000	0.6
1 sq. mile = 2.59×10^6 m^2	

Table E-4.8. Constituent Loss Constant Due to Runoff

All Exposure Scenarios			
$ksr_{WS} \ ' \ \frac{R}{2 \ x \ Z_{WS}} \ x \left(\frac{1}{1\% \ (Kd_s \ x \ BD/2)} \right)$			
Parameter	**Definition**	**Central Tendency**	**High End**
ksr_{WS}	Constituent loss constant due to runoff for watershed (1/yr)		
R	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
2	Soil volumetric water content (mL/cm^3)	Calculated (see Table E-1.17.)	
Z_{WS}	Soil mixing depth in watershed – untilled (cm)	2.5	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
BD	Soil bulk density (g/cm^3)	1.4	
Description			
This equation calculates the constituent loss constant due to runoff from soil.			

Table E-4.9. Constituent Loss Constant Due to Volatilization

All Exposure Scenarios			
$$ksv_{WS} = \left[\frac{3.1536x10^{7} \ x \ H}{Z_{WS} \ x \ Kd_s \ x \ R \ x \ T \ x \ BD}\right] x \left[0.482 \ x \ u^{0.78} \ x \left(\frac{\mu_a}{\rho_a \ x \ D_a}\right)^{-0.67} x \left(\sqrt{\frac{4 \ x \ A_{WS}}{\pi}}\right)^{-0.11}\right]$$			
Parameter	**Definition**	**Central Tendency**	**High End**
ksv_{WS}	Constituent loss constant due to volatilization for watershed (1/yr)		
$3.1536x10^{7}$	Conversion constant (s/yr)		
H	Henry's law constant (atm-m^3/mol)	Chemical specific (see Appendix A)	
Z_{WS}	Soil mixing depth in watershed – untilled (cm)	2.5	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical specific (see Appendix A)	
R	Universal gas constant (atm-m^3/mol-K)	$8.205x10^{-5}$	
T	Ambient air temperature (K)	Met Specific (See Table 2-1 of Report)	
BD	Soil bulk density (g/cm^3)	1.4	
u	Average annual windspeed (m/s)	Met Specific (See Table 2-1 of Report)	
μ_a	Viscosity of air (g/cm-s)	$1.81x10^{-4}$	
ρ_a	Density of air (g/cm^3)	$1.2x10^{-3}$	
D_a	Diffusivity of constituent in air (cm^2/s)	Chemical specific (see Appendix A)	
A_{WS}	Total watershed surface area (m^2)	$2.93x10^{9}$	
Description			
This equation calculates the constituent loss constant due to volatilization from soil.			

Table E-4.10. Total Waterbody Load

Fisher Scenario

$$L_T = L_{Dep} + L_{Dif} + L_{RI} + L_R + L_E$$

Parameter	Definition	Central Tendency	High End
L_T	Total constituent load to the waterbody (g/yr)		
L_{Dep}	Total (wet and dry) particle phase and wet vapor phase direct deposition load to waterbody (g/yr)	Calculated (see Table E-4.11.)	
L_{Dif}	Vapor phase constituent diffusion (dry deposition) load to waterbody (g/yr)	Calculated (see Table E-4.12.)	
L_{RI}	Runoff load from impervious surfaces (g/yr)	Calculated (see Table E-4.16.)	
L_R	Runoff load from pervious surfaces (g/yr)	Calculated (see Table E-4.17.)	
L_E	Soil erosion load (g/yr)	Calculated (see Table E-4.19.)	

Description

This equation calculates the total average waterbody load from wet and dry vapor and particle deposition, runoff, and erosion loads.

Table E-4.11. Deposition to Waterbody

Fisher Scenario

$$L_{Dep} = Q \times [\, F_v \times Dywwv + (1 - F_v) \times Dytwp \,] \times WA_w$$

Parameter	Definition	Central Tendency	High End
L_{Dep}	Total (wet and dry) particle phase and wet vapor phase direct deposition load to waterbody (g/yr)		
Q	Source emissions (g/m^2-s)	Waste management scenario-specific	
F_v	Fraction of air in vapor phase (dimensionless)	Chemical specific (see Appendix A)	
Dywwv	Normalized yearly waterbody average wet deposition from vapor phase (s/yr)	Modeled (see Appendix D)	
Dytwp	Normalized yearly waterbody average total (wet and dry) deposition from particle phase (s/yr)	Modeled (see Appendix D)	
WA_w	Waterbody area (m^2)	1.0x10^6	

Description

This equation calculates the average load to the waterbody from direct deposition of wet and dry particles and wet vapors onto the surface of the waterbody.

Table E-4.12. Diffusion Load to Waterbody

Fisher Scenario

$$L_{Dif} = \frac{K_v \; x \; Q \; x \; F_v \; x \; Cywv \; x \; WA_w \; x \; 10^{-6}}{\frac{H}{R \; x \; T_w}}$$

Parameter	Definition	Central Tendency	High End
L_{Dif}	Dry vapor phase constituent diffusion load to waterbody (g/yr)		
K_v	Diffusive mass transfer coefficient (m/yr)	Calculated (see Table E-4.13.)	
Q	Source emissions (g/m^2-s)	Waste management scenario specific	
F_v	Fraction of air concentration in vapor phase (dimensionless)	Chemical specific (see Appendix A)	
Cywv	Normalized yearly waterbody average vapor phase air concentration (mg-s/g-m)	Modeled (see Appendix D)	
WA_w	Waterbody surface area (m^2)	$1.0x10^6$	
10^{-6}	Units conversion factor (g/µg)		
H	Henry's law constant (atm-m^3/mol)	Chemical specific (see Appendix A)	
R	Universal gas constant (atm-m^3/mol-K)	$8.205x10^{-5}$	
T_w	Waterbody temperature (K)	298	

Description

This equation calculates the load to the waterbody due to vapor diffusion.

Table E-4.13. Overall Transfer Rate

Fisher Scenario			
$$K_v = \left[K_L^{-1} + \left(K_G \frac{H}{R \ x \ T_k}\right)^{-1}\right]^{-1} \ x \ \theta^{(T_k - 293)}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
K_v	Overall transfer rate (m/yr)		
K_L	Liquid phase transfer coefficient (m/yr)	Calculated (see Table E-4.14.)	
K_G	Gas phase transfer coefficient (m/yr)	Calculated (see Table E-4.15.)	
H	Henry's Law constant (atm-m^3/mol)	Chemical specific (see Appendix A)	
R	Universal gas constant (atm-m^3/mol-K)	8.205 x 10^{-5}	
T_k	Waterbody temperature (K)	298	
θ	Temperature correction factor (unitless)	1.026	
Description			
This equation calculates the overall transfer rate of constituent from the liquid and gas phases in surface water.			

Table E-4.14. Liquid Phase Transfer Coefficient

Fisher Scenario
- Flowing stream or river - Quiescent lake or pond

$$K_L = \sqrt{\frac{10^{-4} \ x \ D_w \ x \ u}{d_z}} \ x \ 3.15 \ x \ 10^7$$

$$K_L = (C_d^{0.5} \ x \ W) \ x \left(\frac{\rho_a}{\rho_w}\right)^{0.5} x \left(\frac{k^{0.33}}{\lambda_2}\right) x \left(\frac{\mu_w}{\rho_w \ x \ D_w}\right)^{-0.67} x \ 3.15x10^7$$

$$\rho_w = 1 - 8.8 \ x \ 10^{-5} \ x \ (T_k - 273)$$

Parameter	Definition	Central Tendency	High End
K_L	Liquid phase transfer coefficient (m/yr)		
D_w	Diffusivity of chemical in water (cm^2/s)	Chemical specific (see Appendix A)	
u	Current velocity (m/s)	0.7	
d_z	Total waterbody depth (m)	Calculated (d_w+d_b)	
C_d	Drag coefficient (unitless)	0.0011	
W	Wind velocity, 10 m above water surface (m/s)	Met Specific (See Table 2-1 of Report)	
ρ_a	Density of air corresponding to water temperature (g/cm^3)	1.2×10^{-3}	
ρ_w	Density of water corresponding to water temperature (g/cm^3)	Calculated	
k	von Karman's constant (unitless)	0.4	
λ_2	Dimensionless viscous sublayer thickness	4	
μ_w	Viscosity of water corresponding to the water temperature (g/cm-s)	1.69×10^{-2}	
$3.15x10^7$	Conversion constant (s/yr)		
10^{-4}	Units conversion factor (m^2/cm^2)		
T_K	Waterbody temperature (K)	298	

Description
This equation calculates the transfer rate of constituent from the liquid phase for a flowing or quiescent system.

Table E-4.15. Gas Phase Transfer Coefficient

Fisher Scenario

- Flowing stream or river

$$K_G = 36500\ m/yr$$

- Quiescent lake or pond

$$K_G = (C_d^{0.5}\ x\ W)\ x \left(\frac{k^{0.33}}{\lambda_2}\right) x \left(\frac{\mu_a}{\rho_a\ x\ D_a}\right)^{-0.67} x\ 3.15x10^7$$

Parameter	Definition	Central Tendency	High End
K_G	Gas phase transfer coefficient (m/yr)		
C_d	Drag coefficient (unitless)	0.0011	
W	Wind velocity, 10 m above water surface (m/s)	Met Specific (See Table 2-1 of Report)	
k	von Karman's constant (unitless)	0.4	
λ_2	Dimensionless viscous sublayer thickness (unitless)	4	
μ_a	Viscosity of air corresponding to the air temperature (g/cm-s)	1.81×10^{-4}	
ρ_a	Density of air corresponding to water temperature (g/cm^3)	1.2×10^{-3}	
D_a	Diffusivity of chemical in air (cm^2/s)	Chemical specific (see Appendix A)	
$3.15x10^7$	Conversion constant (s/yr)		

Description

This equation calculates the transfer rate of constituent from the gas phase for a flowing or quiescent system.

Table E-4.16. Impervious Runoff Load to Waterbody

Fisher Scenario			
$L_{RI} = Q \; x \; [\, F_v \; x \; Dywwv + (1.0 - F_v) \; x \; Dytwp \,] \; x \; A_I$			
Parameter	**Definition**	**Central Tendency**	**High End**
L_{RI}	Impervious surface runoff load (g/yr)		
A_I	Impervious watershed area receiving pollutant deposition (m^2)	2.05×10^9	
Q	Source emissions (g/m^2-s)	Waste mgt. scenario specific	
F_v	Fraction of air concentration in vapor phase (dimensionless)	Chemical specific (see Appendix A)	
Dywwv	Normalized yearly watershed average wet deposition from vapor phase (s/yr)	Modeled	
Dytwp	Normalized yearly watershed average total (wet and dry) deposition from particle phase (s/yr)	Modeled	
Description			
This equation calculates the average runoff load to the waterbody from impervious surfaces in the watershed from which runoff is conveyed directly to the waterbody.			

Table E-4.17. Pervious Runoff Load to Waterbody

Fisher Scenario

$$L_R \;'\; R \ x \ (A_{WS} \ \& \ A_I) \ x \ \frac{S_C \ x \ BD}{2 \ \% \ Kd_s \ x \ BD} \ x \ 0.01$$

Parameter	Definition	Central Tendency	High End
L_R	Pervious surface runoff load (g/yr)		
R	Average annual surface runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
S_c	Weighted average constituent concentration in total watershed soils (watershed and sub-basin) based on surface area (mg/kg)	Calculated (see Table E-4.18.)	
BD	Soil bulk density (g/cm^3)	1.4	
Kd_s	Soil-water partition coefficient (L/kg) or (cm^3/g)	Chemical specific (see Appendix A)	
A_{WS}	Total watershed area (m^2)	2.93×10^9	
A_I	Impervious watershed area receiving constituent deposition (m^2)	2.05×10^9	
0.01	Units conversion factor (kg-cm^2/mg-m^2)		
2	Volumetric soil water content (cm^3/cm^3)	Calculated (see Table E-1.17.)	

Description

This equation calculates the average runoff load to the waterbody from pervious soil surfaces in the watershed.

Table E-4.18. Constituent Concentration in Total Watershed Soils Based on Surface Area

All Exposure Scenarios

$$S_C = \frac{A_S \times C_0 + A_F \times C_R + A_{B/Surr} \times C_{B/Surr} + (A_{WS} - A_S - A_{B/Surr} - A_F) \times C_{WS}}{A_{WS}}$$

Parameter	Definition	Central Tendency	High End
S_C	Weighted average constituent concentration in total watershed soils (watershed and sub-basin soils) based on surface area (mg/kg)		
A_S	Area of source (m^2)	Waste management scenario specific	
C_0	Source constituent concentration (mg/kg)	Chemical specific	
A_F	Area of residential plot (m^2)	5,100	
C_R	Constituent concentration in residential plot - Adult resident (mg/kg)	Calculated (see Table E-1.1.)	
$A_{B/Surr}$	Area of buffer and surrounding areas (m^2)	Calculated (see Table E-1.5.)	
$C_{B/Surr}$	Buffer and surrounding area constituent concentration (mg/kg)	Calculated (see Table E-1.11.)	
A_{WS}	Area of entire watershed (m^2)	2.93×10^9	
C_{WS}	Watershed constituent concentration (mg/kg)	Calculated (see Table E-4.1.)	

Description

This equation is used to calculate the weighted average constituent concentration in the total watershed soils, using the constituent concentration in the watershed soils and the constituent concentration in each of the areas within the sub-basin (e.g., source, residential plot, and buffer and surrounding area).

Table E-4.19. Erosion Load to Waterbody

Fisher Scenario			
$$L_E = X_{e,ws} \ x \ (A_{WS} - A_I) \ x \ SD_{WS} \ x \ ER \ x \ \frac{S_{c,soil} \ x \ Kd_s \ x \ BD}{\theta + Kd_s \ x \ BD} \ x \ 0.001$$			
Parameter	**Definition**	**Central Tendency**	**High End**
L_E	Constituent load via soil erosion load (g/yr)		
$X_{e,WS}$	Unit soil loss from the watershed (kg/m^2/yr)	Calculated (see Table E-4.6)	
$S_{c,soil}$	Weighted average total watershed soil (watershed and sub-basin) concentration based on sediment transport (mg/kg)	Calculated (see Table E-4.20.)	
BD	Soil bulk density (g/cm^3)	1.4	
θ	Volumetric soil water content (cm^3/cm^3)	Calculated (see Table E-1.17)	
Kd_s	Soil-water partition coefficient (L/kg) or (cm^3/g)	Chemical specific (see Appendix A)	
A_{WS}	Total watershed area (m^2)	2.93×10^9	
A_I	Impervious watershed area (m^2)	2.05×10^9	
SD_{WS}	Sediment delivery ratio for watershed (unitless)	Calculated (see Table E-4.7.)	
ER	Soil enrichment ratio (unitless)	Metals = 1	
0.001	Units conversion factor (g/mg)		
Description			
This equation calculates the load to the waterbody from soil erosion.			

Table E-4.20. Weighted Average Soil Concentration Based on Eroded Soil Contributions

All Exposure Scenarios

$$S_{c,\,soil} = \left[\frac{(X_{e,S} \times A_S \times C_0 \times SD_{SB}) + (X_{e,B/Surr} \times A_{B/Surr} \times C_{B/Surr} \times SD_{SB}) + (X_{e,R} \times A_F \times C_R \times SD_{SB})}{X_{e,WS} \times A_{WS} \times SD_{WS}}\right]$$

$$+ \frac{(A_{ws} - A_s - A_{B/Surr} - A_F) \times C_{ws}}{A_{ws}}$$

Parameter	Definition	Input Value
$S_{c,\,soil}$	Weighted average total watershed soil (watershed and sub-basin) concentration based on eroded soil transport (mg/kg)	
$X_{e,s}$	Unit soil loss from source (kg/m^2/yr)	Calculated (see Table E-1.3.)
A_S	Source area (m^2)	Waste management scenario specific
C_0	Source constituent concentration (mg/kg)	Constituent specific
SD_{SB}	Sediment delivery ratio for sub-basin (unitless)	Calculated (see Table E-1.4.)
$X_{e,B/Surr}$	Unit soil loss from buffer and surrounding areas (kg/m^2/yr)	Calculated (see Table E-1.20.)
$A_{B/Surr}$	Buffer and surrounding areas (m^2)	Calculated (see Table E-1.5.)
$C_{B/Surr}$	Buffer and surrounding areas constituent concentration (mg/kg)	Calculated (see Table E-1.11.)
$X_{e,R}$	Unit soil loss from field (kg/m^2/yr)	Calculated (see Table E-1.28.)
A_F	Area of residential plot (m^2)	5,100
C_R	Constituent concentration in residential plot (mg/kg)	Calculated (see Table E-1.1.)
$X_{e,WS}$	Unit soil loss from the watershed (kg/m^2/yr)	Calculated (see Table E-4.6.)
A_{WS}	Total watershed area (m^2)	2.93×10^9
SD_{WS}	Sediment delivery ratio for watershed (unitless)	Calculated (see Table E-4.7.)
C_{WS}	Watershed constituent concentration (mg/kg)	Calculated (see Table E-4.1.)

Description

This equation calculates the average concentration of delivered sediment for the watershed allowing for different unit soil loss factors and sediment delivery ratios for each of the modeled areas.

Table E-4.21. Total Waterbody Concentration

Fisher Scenario

$$C_{wtot} = \frac{L_T}{Vf_x \times f_{water} + k_{wt} \times WA_w \times (d_w + d_b)}$$

Parameter	Definition	Input Value
C_{wtot}	Total water body concentration, including water column and bed sediment (mg/L) or (g/(m^3)	
L_T	Total chemical load into water- body, including deposition, runoff, and erosion (g/yr)	Calculated (see Table E-4.10.)
Vf_x	Average volumetric flow rate through water body (m^3/yr)	$3x10^8$
f_{water}	Fraction of total water body constituent concentration that occurs in the water column (unitless)	Calculated (see Table E-4.22.)
k_{wt}	Overall total waterbody dissipation rate constant (1/yr)	Calculated (see Table E-4.23.)
WA_w	Waterbody surface area (m^2)	$1.0x10^6$
d_w	Depth of water column (m)	0.64
d_b	Depth of upper benthic layer (m)	0.03

Description

This equation calculates the total waterbody concentration, including both the water column and the bed sediment.

Table E-4.22. Fraction in Water Column and Benthic Sediment

Fisher Scenario

$$f_{water} = \frac{(1 + Kd_{sw} \times TSS \times 10^{-6}) \times d_w / d_z}{(1 + Kd_{sw} \times TSS \times 10^{-6}) \times d_w/d_z + (\theta_{bs} + Kd_{bs} \times BS) \times d_b / d_z}$$

$$f_{benth} = 1 - f_{water}$$

Parameter	Definition	Central Tendency	High End
f_{water}	Fraction of total waterbody constituent concentration that occurs in the water column (unitless)		
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)	Chemical specific (see Appendix A)	
TSS	Total suspended solids (mg/L)	80	
10^{-6}	Conversion factor (kg/mg)		
d_w	Depth of the water column (m)	0.64	
d_z	Total waterbody depth (m)	Calculated (d_w+d_b)	
d_b	Depth of the upper benthic layer (m)	0.03	
θ_{bs}	Bed sediment porosity (L_{water}/L)	0.6	
Kd_{bs}	Bed sediment/sediment pore water partition coefficient (L/kg) or (g/cm^3)	Chemical-specific (see Appendix A)	
BS	Bed sediment concentration (g/cm^3)	1.0	
f_{benth}	Fraction of total waterbody constituent concentration that occurs in the benthic sediment (unitless)		

Description

These equations calculate the fraction of total waterbody concentration occurring in the water column and the bed sediments.

Table E-4.23. Overall Total Waterbody Dissipation Rate Constant

Fisher Scenario			
$$k_{wt} = f_{water} \times k_v + k_b$$			
Parameter	**Definition**	**Central Tendency**	**High End**
k_{wt}	Overall total waterbody dissipation rate constant (1/yr)		
f_{water}	Fraction of total waterbody constituent concentration that occurs in the water column	Calculated (see Table E-4.22.)	
k_v	Water column volatilization rate constant (1/yr)	Calculated (see Table E-4.24.)	
k_b	Benthic burial rate constant (1/yr)	Calculated (see Table E-4.25.)	
Description			
This equation calculates the overall dissipation rate of constituent in surface water due to volatilization and benthic burial.			

Table E-4.24. Water Column Volatilization Loss Rate Constant

Fisher Scenario

$$k_v = \frac{K_v}{d_z \; x \; (1 + Kd_{sw} \; x \; TSS \; x \; 10^{-6})}$$

Parameter	Definition	Central Tendency	High End
k_v	Water column volatilization rate constant (1/yr)		
K_v	Overall transfer rate (m/yr)	Calculated (see Table E-4.13.)	
d_z	Total waterbody depth (m)	Calculated (d_w+d_b)	
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)	Chemical specific (see Appendix A)	
TSS	Total suspended solids (mg/L)	80	
10^{-6}	Conversion factor (kg/mg)		

Description

This equation calculates the water column constituent loss due to volatilization.

0

Table E-4.25. Benthic Burial Rate Constant

Fisher Scenario			
$$k_b = f_{benth} \times \left(\frac{W_b}{d_b}\right)$$			
Parameter	**Definition**	**Central Tendency**	**High End**
k_b	Benthic burial rate constant (1/yr)		
f_{benth}	Fraction of total waterbody constituent concentration that occurs in the benthic sediment	Calculated (see Table E-4.22)	
W_b	Burial rate (m/yr)	Calculated (see Table E-4.26)	
d_b	Depth of upper benthic sediment layer (m)	0.03	
Description			
This equation calculates the water column constituent loss due to burial in benthic sediment.			

Table E-4.26. Benthic Burial Rate Constant

Fisher Scenario

$$W_b = W_{dep} \times \left(\frac{TSS \times 10^{-6}}{BS} \right)$$

Parameter	Definition	Central Tendency	High End
W_b	Benthic burial rate constant (m/yr)		
W_{dep}	Deposition rate to bottom sediment (m/yr)	Calculated (see Table E-4.27)	
TSS	Total suspended solids (mg/L)	80	
10^{-6}	Units conversion factor (kg/mg)		
BS	Bed sediments concentration (kg/L)	1	

Description

This equation is used to determine the loss of constituent from the benthic sediment layer.

Table E-4.27. Deposition Rate to Bottom Sediment

Fisher Scenario

$$W_{dep} = \left(\frac{X_{e,ws} \ x \ A_{ws} \ x \ SD_{ws} \ x \ 1000 - Vf_x \ x \ TSS}{WA_w \ x \ TSS} \right)$$

Parameter	Definition	Central Tendency	High End
W_{dep}	Deposition rate to bottom sediment (m/yr)		
$X_{e,ws}$	Unit soil loss from the watershed (kg/m^2/yr)	Calculated (see Table E-4.6)	
A_{ws}	Area of watershed (m^2)	2.93×10^9	
SD_{ws}	Watershed sediment delivery ratio (unitless)	Calculated (see Table E-4.7)	
Vf_x	Average volumetric flow rate (m^3/yr)	3.0×10^8	
TSS	Total suspended solids (g/m^3)	80	
1000	Units conversion factor (g/kg)		
WA_w	Waterbody surface area (m^2)	1×10^6	

Description

This equation is used to determine the loss of constituent from the waterbody as it deposits onto the benthic sediment.

Table E-4.28. Total Water Column Concentration

Fisher Scenario

$$C_{wt} = f_{water} \times C_{wtot} \times \frac{d_w + d_b}{d_w}$$

Parameter	Definition	Central Tendency	High End
C_{wt}	Total concentration in water column (mg/L)		
f_{water}	Fraction of total water body constituent concentration that occurs in the water column (unitless)	Calculated (see Table E-4.22.)	
C_{wtot}	Total water concentration in surface water system, including water column and bed sediment (mg/L)	Calculated (see Table E-4.21.)	
d_b	Depth of upper benthic layer (m)	0.03	
d_w	Depth of the water column (m)	0.64	

Description

This equation calculates the total water column concentration of constituent; this includes both dissolved constituent and constituent sorbed to suspended solids.

Table E-4.29. Dissolved Water Concentration

Fisher Scenario			
$$C_{dw} = \frac{C_{wt}}{1 + Kd_{sw} \times TSS \times 10^{-6}}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
C_{dw}	Dissolved phase water concentration (mg/L)		
C_{wt}	Total concentration in water column (mg/L)	Calculated (see Table E-4.28.)	
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)	Chemical specific (see Appendix A)	
10^{-6}	Units conversion factor (kg/mg)		
TSS	Total suspended solids (mg/L)	80	
Description			
This equation calculates the concentration of constituent dissolved in the water column.			

Table E-4.30. Concentration Sorbed to Bed Sediment

Fisher Scenario

$$C_{sb} = f_{benth} \ x \ C_{wtot} \ x \ \frac{Kd_{bs}}{\theta_{bs} + Kd_{bs} \ x \ BS} \ x \ \frac{d_w + d_b}{d_b}$$

Parameter	Definition	Central Tendency	High End
C_{sb}	Concentration sorbed to bed sediments (mg/kg)		
f_{benth}	Fraction of total waterbody constituent concentration that occurs in the bed sediment (unitless)	Calculated (see Table E-4.22.)	
C_{wtot}	Total water concentration in surface water system, including water column and bed sediment (mg/L)	Calculated (see Table E-4.21.)	
d_w	Total depth of water column (m)	0.64	
d_b	Depth of the upper benthic layer (m)	0.03	
θ_{bs}	Bed sediment porosity (unitless)	0.6	
Kd_{bs}	Bed sediment/sediment pore water partition coefficient (L/kg)	Chemical specific (see Appendix A)	
BS	Bed sediment concentration (kg/L)	1.0	

Description

This equation calculates the concentration of constituent sorbed to bed sediments.

Table E-4.31. Fish Concentration from Dissolved Water Concentration

Fisher Scenario			
$C_{fish} ' C_{dw} \; x \; BCF$			
Parameter	**Definition**	**Central Tendency**	**High End**
C_{fish}	Fish concentration (mg/kg)		
C_{dw}	Dissolved water concentration (mg/L)	Calculated (see Table E-4.29.)	
BCF	Bioconcentration factor (L/kg)	Chemical specific (see Appendix A)	
Description			
This equation calculates fish concentration from dissolved water concentration using a bioconcentration factor.			

Table E-4.32. Fish Concentration from Total Water Column Concentration

Fisher Scenario			
$$C_{fish} = C_{wt} \times BAF$$			
Parameter	**Definition**	**Central Tendency**	**High End**
C_{fish}	Fish concentration (mg/kg)		
C_{wt}	Total water column concentration (mg/L)	Calculated (see Table E-4.28.)	
BAF	Bioaccumulation factor (L/kg)	Chemical specific (see Appendix A)	
Description			
This equation calculates fish concentration from total water column concentration using a bioaccumulation factor.			

Table E-5.1. Contaminant Intake from Soil		
$$I_{soil} = Sc \cdot CR_{soil} \cdot F_{soil}$$		
Parameter	**Description**	**Value**
I_{soil}	Daily intake of contaminant from soil (mg/d)	
Sc	Average soil concentration of pollutant over exposure duration (mg/kg)	calculated
CR_{soil}	Consumption rate of soil (kg/d)	varies (See Table 5-4 of Report)
F_{soil}	Fraction of consumed soil contaminated (unitless)	(See Table 5-6 of Report)
Description		
This equation calculates the daily intake of contaminant from soil consumption. The soil concentration will vary with each scenario, and the soil consumption rate varies for children and adults.		

Table E-5.2. Contaminant Intake from Exposed Vegetable Intake

$$I_{ev} = (Pd + Pv + Pr) \cdot CR_{ag} \cdot F_{ag}$$

Parameter	Description	Value
I_{ag}	Daily intake of contaminant from exposed vegetables (mg/kg Fw)	
Pd	Concentration in exposed vegetables due to deposition (mg/kg Dw)	calculated
Pv	Concentration in exposed vegetables due to air-to-plant transfer (mg/kg Dw)	calculated
Pr	Concentration in exposed vegetables due to root uptake (mg/kg Dw)	calculated
CR_{ag}	Consumption rate of exposed vegetables (kg Dw/d)	varies (See Table 5-4 of Report)
F_{ag}	Fraction of exposed vegetables contaminated (unitless)	varies (See Table 5-6 of Report)

Description

This equation calculates the daily intake of contaminate from ingestion of exposed vegetables. The consumption rate varies for children and adults. The contaminated fraction and the concentration in exposed vegetables will vary with each scenario.

Table E-5.3. Contaminant Intake from Exposed Fruit Intake

$$I_{ef} = (Pd + Pv + Pr) \cdot CR_{ag} \cdot F_{ag}$$

Parameter	Description	Value
I_{ef}	Daily intake of contaminant from exposed fruit (mg/kg Fw)	
Pd	Concentration in exposed fruit due to deposition (mg/kg Dw)	calculated
Pv	Concentration in exposed fruit due to air-to-plant transfer (mg/kg Dw)	calculated
Pr	Concentration in exposed fruit due to root uptake (mg/kg Dw)	calculated
Cr_{ag}	Consumption rate of exposed fruit (kg Dw/d)	varies (See Table 5-4 of Report)
F_{ag}	Fraction of exposed fruit contaminated (unitless)	varies (See Table 5-6 of Report)

Description

This equation calculates the daily intake of contaminate from ingestion of exposed fruit. The consumption rate varies for children and adults. The contaminated fraction and the concentration in exposed fruit will vary with each scenario.

Table E-5.4. Contaminant Intake from Root Vegetable Intake

$$I_{ev} = Pr_{bg} \cdot CR_{rv} \cdot F_{rv}$$

Parameter	Description	Value
I_{rv}	Daily intake of contaminant from root vegetables for dioxins (mg/kg Fw); metals (mg/kg Dw)	
Pr_{rv}	Concentration in root vegetables due to deposition for dioxins (mg/kg Fw); metals (mg/kg Dw)	calculated
Cr_{rv}	Consumption rate of root vegetables for dioxins (kg Fw/d); metals (kg Dw/d)	varies (See Table 5-4 of Report)
F_{rv}	Fraction of root vegetables contaminated (unitless)	varies (See Table 5-6 of Report)

Description

This equation calculates the daily intake of contaminate from ingestion of exposed vegetables. The consumption rate varies for children and adults. The contaminated fraction and the concentration in exposed vegetables will vary with each scenario.

Table E-5.5. Contaminant Intake from Beef and Milk

$$I_i = A_i \cdot CR_i \cdot F_i$$

Parameter	Description	Value
I_i	Daily intake of contaminant from animal tissue *i* (mg/d)	
A_i	Concentration in animal tissue *i* (mg/kg Fw) - for Dioxins and (mg/kg Dw) - for Cadmium	calculated
CR_i	Consumption rate of animal tissue *i* (kg Fw/d) - for Dioxins and (Kg Dw/d) - for Cadmium	varies (See Table 5-4 of Report)
F_i	Fraction of animal tissue *i* contaminated (unitless)	varies (See Table 5-6 of Report)

Description

This equation calculates the daily intake of contaminate from ingestion of animal tissue (where the "*i*" in the above equation refers to beef and milk). The consumption rate varies for children and adults and for the type of animal tissue.

Table E-5.6. Contaminant Intake from Fish		
$$I_{fish} = C_{fish} \cdot CR_{fish} \cdot F_{fish}$$		
Parameter	**Description**	**Value**
I_{fish}	Daily intake of contaminant from fish (mg/d)	
C_{fish}	Concentration in fish (mg/kg)	calculated
Cr_{fish}	Consumption rate of fish (kg/d)	varies (See Table 5-4 of Report)
F_{fish}	Fraction of fish contaminated (unitless)	(See Table 5-6 of Report)
Description		
This equation calculates the daily intake of contaminate from ingestion of fish.		

Table E-5.7. Total Daily Intake

Adult and Child Home Gardener

$$I = I_{soil} + I_{ev} + I_{ef} + I_{rv}$$

Farmer

$$I = I_{soil} + I_{ev} + I_{beef} + I_{milk} + I_{ef} + I_{rv}$$

Fisher

$$I = I_{fish}$$

Parameter	Description	Value
I	Total daily intake of contaminant (mg/d)	
I_{soil}	Daily intake of contaminant from soil (mg/d)	calculated (see Appendix E-5.1)
I_{ev}	Daily intake of contaminant from exposed vegetables	calculated (see Appendix E-5.2)
I_{ef}	Daily intake of contaminant from exposed fruit (mg/d)	calculated (see Appendix E -5.3)
I_{rv}	Daily intake of contaminant from root vegetables	calculated (see Appendix E -5.4)
I_{beef}, I_{milk}	Daily intake of contaminant from animal tissue (mg/d)	calculated (see Appendix E -5.5)
I_{fish}	Daily intake of contaminant from fish (mg/d)	calculated (see Appendix E -5.6)

Description

This equation calculates the daily intake of contaminant on a pathway by pathway basis.

Table E-5.7. (Continued) Total Daily Intake

$$I = I_{soil} + I_{ev} + I_{beef} + I_{milk} + I_{fish} + I_{ef} + I_{rv}$$

Parameter	Description	Value
I	Total daily intake of contaminant (mg/d)	
I_{soil}	Daily intake of contaminant from soil (mg/d)	calculated (see Table E-5.1)
I_{ev}	Daily intake of contaminant from exposed vegetables (mg/d)	calculated (see Table E-5.2)
I_{ef}	Daily intake of contaminant from exposed fruit (mg/d)	calculated (see Table E-5.3)
I_{rv}	Daily intake of contaminant from root vegetables fruit (mg/d)	calculated (see Table E-5.4)
I_{beef}, I_{milk}	Daily intake of contaminant from animal tissue (mg/d)	calculated (see Table E-5.5)
I_{fish}	Daily intake of contaminant from fish (mg/d)	calculated (see Table E-5.6)

Description

This equation calculates the daily intake of contaminate via all indirect pathways.

Table E-5.8. Individual Cancer Risk: Carcinogens		

$$Cancer\ Risk = \frac{I \cdot ED \cdot EF \cdot CSF}{BW \cdot AT \cdot 365}$$

Parameter	Description	Value
Cancer Risk	Individual lifetime cancer risk (unitless)	
I	Total daily intake of contaminant (mg/d)	calculated (see Table E-5.6)
ED	Exposure duration (yr)	varies See Exposure
EF	Exposure frequency (day/yr)	350
BW	Body weight (kg)	adult: 70 child: varies
AT	Averaging time (yr)	70
365	Units conversion factor (day/yr)	
CSF	Oral cancer slope factor (per mg/kg/d)	chemical-specific (see Appendix A)

Description

This equation calculates the individual cancer risk from indirect exposure to carcinogenic chemicals. The body weight varies for the child. The exposure duration varies for different scenarios.

Table E-5.9. Hazard Quotient: Noncarcinogens		

$$HQ = \frac{I}{BW \cdot RfD}$$

Parameter	Description	Value
HQ	Hazard quotient (unitless)	
I	Total daily intake of contaminant (mg/d)	calculated (see Table E-5.6)
BW	Body weight (kg)	adult: 70 child: varies
RfD	Reference Dose (mg/kg/d)	chemical-specific (see Appendix A)

Description

This equation calculates the hazard quotient for indirect exposure to noncarcinogenic chemicals. The body weight varies for the child.

Table E-5.10 Total Cancer Risk for Farmer Scenario: Carcinogens

$$Total\ Cancer\ Risk = \sum_i Cancer\ Risk_i$$

Parameter	Definition	Value
Total Cancer Risk	Total individual lifetime cancer risk for all chemicals (unitless)	
Cancer $Risk_i$	Individual lifetime cancer risk for chemical carcinogen I (unitless)	calculated (see Table E-5.7)

Description

For carcinogens, cancer risks are added across all carcinogenic chemicals.

Table E-5.11 Hazard Index for Specific Organ Effects for Farmer Scenario: Noncarcinogens

$$HI_j = \sum_i HQ_i$$

Parameter	Definition	Value
Hi_j	Hazard index for specific organ effect j (unitless)	
HQ_i	Hazard quotient for chemical I with specific organ effect j (unitless)	calculated (see Table E-5.9)

Description

For noncancer health effects, hazard quotients are added across chemicals when they target the same organ to calculate an overall hard index.

Table E-6.1 Inhalation Cancer Risk for Individual Chemicals from Unit Risk Factor: Carcinogens		
$$Cancer\ Risk = C_a \cdot URF$$		
Parameter	**Description**	**Value**
Cancer Risk	Individual Lifetime cancer risk (unitless)	
C_a	Concentration in air (μg/m^3)	calculated
UFR	Inhalation Unit Risk Factor (per μg/m^3)	chemical-specific (see Appendix A)
Description		
This equation calculates the inhalation cancer risk for individual constituents using the Unit Risk Factor.		

Table E-6.2. Inhalation Cancer Risk for Individual Chemicals from Carcinogenic Slope Factor: Carcinogens

$$Cancer\ Risk = ADI \times CSF_{inh}$$

$$ADI = \frac{C_a \times IR \times ET \times EF \times ED \times 0.001\ \ mg/\mu g}{BW \times AT \times 365\ \ day/yr}$$

Parameter	Description	Value
Cancer Risk	Individual lifetime cancer risk (unitless)	
ADI	Average daily intake via inhalation (mg/kg/day)	
IR	Inhalation rate (m^3/hr)	Varies (See Table 5-4 of Report)
ET	Exposure time (hr/day)	24
EF	Exposure frequency (day/yr)	350
BW	Body weight (kg)	Adult = 70 Child = varies
AT	Averaging time (yr)	70
CSF_{inh}	Inhalation Carcinogenic slope Factor (per mg/kg/day)	chemical-specific (see Appendix A)

Description

This equation calculates the inhalation cancer risk for individual constituents using the Carcinogenic Slope Factor.

Table E-6.3. Inhalation Hazard Quotient for Individual Chemicals: Noncarcinogens

$$HQ = \frac{C_a \cdot 0.001 \ mg/\mu g}{RfC}$$

Parameter	Description	Value
HQ	Hazard quotient (unitless)	
C_a	Concentration in air (µg/m^3)	calculated
RfC	Reference concentration (mg/m^3)	chemical-specific (see Appendix A)

Description

This equation calculates the inhalation hazard quotient for individual constituents.

Table E-6.4 Total Inhalation Cancer Risk: Carcinogens		
$$Total\ Cancer\ Risk = \sum_i Cancer\ Risk_i$$		
Parameter	**Definition**	**Value**
Total Cancer Risk	Total individual lifetime cancer risk for all chemicals (unitless)	
Cancer $Risk_i$	Individual lifetime cancer risk for chemical carcinogen I (unitless)	calculated (see Tables E-6.1, E-6.2)
Description		
For carcinogens, cancer risks are added across all carcinogenic chemicals.		

Table E-6.5 Hazard Index for Inhalation: Noncarcinogens		
$$HI_{inh} = \sum_i HQ_i$$		
Parameter	**Definition**	**Value**
Hi_{inh}	Hazard index for inhalation (unitless)	
HQ_i	Hazard quotient for chemical I (unitless)	calculated (see Table E-6.3)
Description		
For noncancer health effects, hazard quotients are added across chemicals when the same organ to calculate an overall hazard index.		

Appendix F

Soil Amendment Equations

Table F-1.1. Constituent Concentration Due to Erosion in Buffer Field

All Exposure Scenario			
$$C_{BF} = \frac{SL_{BF} \times C_F \times ER}{ks_{BF} \times M_{BF}}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
C_{BF}	Constituent concentation in the buffer field (mg/kg)		
$SL_{F,BF}$	Soil load delivered to buffer field for material orginating from source field (kg/yr)	Calculated (see Table F-1.2.)	
C_F	Source field constituent concentration (mg/kg)	Chemical-specific	
ks_{BF}	Constituent loss constant for buffer field (1/yr)	Calculated (see Table F-1.6.)	
M_{BF}	Mass of soil in mixing depth of buffer field (kg)	Calculated (see Table F-1.14.)	
Description			
This equation is used to calculate the constituent concentration in the buffer field as a result of erosion from the source field. Buffer field is located in the area existing between the source field and the surface water body.			

Table F-1.2. Soil Load Delivered to Buffer Field for Material Originating from Source Field

All Exposure Scenarios			
$$SL_{F,BF} = X_{e,F} \ x \ A_B \ x \ (1 - SD_{SB}) \ x \left(\frac{A_{BF}}{A_F + A_{BF}} \right)$$			
Parameter	**Definition**	**Central Tendency**	**High End**
$SL_{F,BF}$	Soil load delivered to buffer field for material originating from source field (kg/yr)		
$X_{e,F}$	Unit soil loss from source field (kg/m^2-yr)	Calculated (see Table F-1.3.)	
A_F	Area of source field (m^2)	Ag field = 902,450 Home garden = 5,100	
SD_{SB}	Sub-basins ediment delivery ratio (unitless)	Calculated (see Table F-1.5.)	
A_{BF}	Area of buffer field (m^2)	Calculated (see Table F-1.4.)	
Description			
This equation is used to calculate the load of eroded soil originating from the source field of interest that is deposited onto the buffer field.			

Table F-1.3. Universal Soil Loss Equation (USLE) for the Source Field

All Exposure Scenarios

$$X_{e,F} = R_F \times K_F \times LS_F \times C_F \times P_F \times \frac{907.18}{4047}$$

Parameter	Definition	Central Tendency	High End
$X_{e,F}$	Unit soil loss from the source field ($kg/m^2/yr$)		
R_F	USLE rainfall (or erosivity) factor (1/yr)	Met Specific (See Table 2-1 of Report)	
K_F	USLE erodibility factor (ton/acre)	0.3	
LS_F	USLE length-slope factor (unitless)	1.5	
C_F	USLE cover management factor (unitless)	0.15	
P_F	USLE supporting practice factor (unitless)	1	
907.18	Conversion factor (kg/ton)		
4047	Conversion factor (m^2/acre)		

Description

This equation calculates the soil loss rate from the source field, using the Universal Soil Loss Equation; the result is used in the soil erosion load equation.

Table F-1.4. Buffer Field Area

All Exposure Scenarios

$$A_{BF} = d_b \times \sqrt{A_F}$$

Parameter	Definition	Central Tendency	High End
A_{BF}	Area of buffer field (m^2)		
d_b	Distance between field source and waterbody side-length of buffer field (m)	300	75
A_F	Area of source field of interest (m^2)	Ag. Field = 902,450 Home garden = 5,100	

Table F-1.5. Sub-basin Sediment Delivery Ratio

All Exposure Scenarios			
$$SD_{SB} = a \times (A_F + A_{BF})^{-b}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
SD_{SB}	Sub-basin sediment delivery ratio for sub-basin (unitless)		
a	Empirical intercept coefficient	Depends on sub-basin area; see table below	
A_{BF}	Area of buffer field (m^2)	Calculated (see Table F-1.4.)	
A_F	Area of source field of interest (m^2)	Ag. field = 902,450 Home garden = 5,100	
b	Empirical slope coefficient	0.125	
Description			
This equation calculates the sediment delivery ratio for the sub-basin; the result is used in the soil erosion load equation.			

Values for Empirical Intercept Coefficient, a

Sub-basin (A_F+A_{BF})	"a" coefficient (unitless)
≤ 0.1	2.1
1	1.9
10	1.4
100	1.2
1,000	0.6
1 sq. mile = 2.59×10^6 m^2	

Table F-1.6. Constituent Loss Constant

All Exposure Scenarios			
$$ks_{BF} = ksl_{BF} + kse_{BF} + ksr_{BF} + ksg_{BF} + ksv_{BF}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
ks_{BF}	Constituent loss constant due to all processes for the buffer field (1/yr)		
ksl_{BF}	Constituent loss constant due to leaching (1/yr)	Calculated (see Table F-1.7.)	
kse_{BF}	Constituent loss constant due to soil erosion (1/yr)	Calculated (see Table F-1.10.)	
ksr_{BF}	Constituent loss constant due to surface runoff (1/yr)	Calculated (see Table F-1.12.)	
ksg_{BF}	Constituent loss constant due to degradation (1/yr)	Chemical Specific (See Appendix A)	
ksv_{BF}	Constituent loss constant due to volatilization (1/yr)	Calculated (see Table F-1.13.)	
Description			
This equation calculates the constitutent loss constant, which accounts for the loss of constituent from soil by several mechanisms.			

Table F-1.7. Constituent Loss Constant Due to Leaching

All Exposure Scenarios			
$$ksl_{BF} = \frac{P + I - R - E_v}{\theta \; x \; Z_{BF} \; x \; [1.0 + (BD \; x \; Kd_s / \theta)]}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
ksl_{BF}	Constituent loss constant for buffer field due to leaching (1/yr)		
P	Average annual precipitation (cm/yr)	Met Specific (See Table 2-1 of Report)	
I	Average annual irrigation (cm/yr)	0	
R	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
E_v	Average annual evapotranspiration (cm/yr)	Met Specific (See Table 2-1 of Report)	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table F-1.8.)	
Z_{BF}	Soil depth of buffer field from which leaching removal occurs - untilled (cm)	2.5	
BD	Soil bulk density (g/cm^3)	1.4	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
Description			
This equation calculates the constituent loss constant due to leaching from soil.			

Table F-1.8. Soil Volumetric Water Content

All Exposure Scenarios

$$\theta = \theta_s \left[\frac{q}{K_s}\right]^{\frac{1}{2b+3}}$$

Parameter	Definition	Central Tendency	High End
θ	Soil volumetric water content (mL/cm^3)		
θ_s	Soil saturated volumetric water content (mL/cm^3)	0.43	
q	Average annual recharge rate (cm/yr)	Calculated (see Table F-1.9.)	
K_s	Saturated hydraulic conductivity (cm/yr)	808	
b	Soil-specific exponent representing water retention (unitless)	5.4	

Table F-1.9. Average Annual Recharge

All Exposure Scenarios			
$q = P + I - E_v - R_f$			
Parameter	**Definition**	**Central Tendency**	**High End**
q	Average annual recharge rate (cm/yr)		
P	Average annual precipitation (cm/yr)	Met Specific (See Table 2-1 of Report)	
I	Average annual irrigation (cm/yr)	0	
E_v	Average annual evapotranspiration (cm/yr)	Met Specific (See Table 2-1 of Report)	
R_f	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	

Table F-1.10. Constituent Loss Constant Due to Erosion

All Exposure Scenarios			
$$kse_{BF} \; ' \; \frac{0.1 \; x \; ER \; x \; X_{e,BF} \; x \; SD_{SB}}{BD \; x \; Z_{BF}} \; x \; \left(\frac{Kd_s \; x \; BD}{2\% \; (Kd_s \; x \; BD)} \right)$$			
Parameter	**Definition**	**Central Tendency**	**High End**
kse_{BF}	Constituent loss constant for buffer field due to soil erosion (1/yr)		
$X_{e,BF}$	Unit soil loss for buffer field (kg/m^2/yr)	Calculated (see Table F-1.11.)	
2	Soil volumetric water content (mL/cm^3)	Calculated (see Table F-1.8.)	
Z_{BF}	Soil mixing depth for buffer field - untilled (cm)	2.5	
BD	Soil bulk density (g/cm^3)	1.4	
Kd_s	Soil-water partition coefficient (mL/g)	Chemical-specific (see Appendix A)	
SD_{SB}	Sediment delivery ratio for the sub-basin (unitless)	Calculated (see Table F-1.5).	
ER	Constituent enrichment ratio (unitless)	Metals = 1	

Table F-1.11. Universal Soil Loss Equation (USLE) for Buffer Field

All Exposure Scenarios

$$X_{e,BF} = R_{BF} \ x \ K_{BF} \ x \ LS_{BF} \ x \ C_{BF} \ x \ P_{BF} \ x \ \frac{907.18}{4047}$$

Parameter	Definition	Central Tendency	High End
$X_{e,BF}$	Unit soil loss for buffer field (kg/m^2 -yr)		
R_{BF}	USLE rainfall factor (1/yr)	Met Specific (See Table 2-1 of Report)	
K_{BF}	USLE erodibility factor (ton/acre)	Met Specific (See Table 2-1 of Report)	
LS_{BF}	USLE length-slope factor (unitless)	1.5	
C_{BF}	USLE cover factor (unitless)	0.15	
P_{BF}	USLE erosion control practice factor (unitless)	1.0	
907.18	Units conversion factor (kg/ton)		
4047	Units conversion factor (m^2/acre)		

Description

This equation is used to calculate the soil loss rate from the buffer field using the Universal Soil Loss Equation; the result is used in the soil erosion load equation.

Table F-1.12. Constituent Loss Constant Due to Runoff

All Exposure Scenarios			
$$ksr_{BF} = \frac{R}{\theta \times Z_{BF}} \times \left(\frac{1}{1 + (Kd_s \times BD / \theta)} \right)$$			
Parameter	**Definition**	**Central Tendency**	**High End**
ksr_{BF}	Constituent loss constant for buffer field due to runoff (1/yr)		
R	Average annual runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
θ	Soil volumetric water content (mL/cm^3)	Calculated (see Table F-1.8.)	
Z_{BF}	Soil mixing depth of buffer field - untilled (cm)	2.5	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
BD	Soil bulk density (g/cm^3)	1.4	
Description			
This equation calculates the constituent loss constant due to runoff from soil.			

Table F-1.13. Constituent Loss Constant Due to Volatilization

All Exposure Scenarios

$$ksv_{BF} = \left[\frac{3.1536x10^{7}\ x\ H}{Z_{BF}\ x\ Kd_s\ x\ R\ x\ T\ x\ BD}\right] x \left[0.482\ x\ u^{0.78}\ x \left(\frac{\mu_a}{D_a\ x\ D_a}\right)^{-0.67} x \left(\sqrt{\frac{4\ x\ A_{BF}}{B}}\right)^{-0.11}\right]$$

Parameter	Definition	Central Tendency	High End
ksv_{BF}	Constituent loss constant for buffer field due to volatilization (1/yr)		
$3.1536x10^7$	Conversion constant (s/yr)		
H	Henry's law constant (atm-m^3/mol)	Chemical-specific (see Appendix A)	
Z_{BF}	Soil mixing depth of buffer field - untilled (cm)	2.5	
Kd_s	Soil-water partition coefficient (cm^3/g)	Chemical-specific (see Appendix A)	
R	Universal gas constant (atm-m^3/mol-K)	$8.205x10^{-5}$	
T	Ambient air temperature (K)	Met Specific (See Table 2-1 of Report)	
BD	Soil bulk density (g/cm^3)	1.4	
u	Average annual windspeed (m/s)	Met Specific (See Table 2-1 of Report)	
μ_a	Viscosity of air (g/cm-s)	$1.81x10^{-4}$	
D_a	Density of air (g/cm^3)	$1.2x10^{-3}$	
D_a	Diffusivity of constituent in air (cm^2/s)	Chemical-specific (see Appendix A)	
A_{BF}	Surface area of buffer field (m^2)	Calculated (see Table F-1.4.)	

Description

This equation calculates the constituent loss constant due to volatilization from soil.

Table F-1.14. Mass of Soil in Mixing Depth of Buffer Field

All Exposure Scenarios

$$M_{BF} = Z_{BF} \times A_{BF} \times BD \times 10$$

Parameter	Definition	Central Tendency	High End
M_{BF}	Mass of soil in mixing depth of buffer field (kg)		
Z_{BF}	Soil mixing depth for buffer field - untilled (cm)	2.5	
A_{BF}	Area of buffer field (m^2)	Calculated (see Table F-1.4.)	
BD	Soil bulk density (g/cm^3)	1.4	
10	Units conversion factor (cm^2 - kg/m^2 -g)		

Description

This equation is used to calculate the total mass of soil in the buffer field that will be mixing with the mass of eroded material.

Table F-2.1. Total Load to Waterbody

Fisher Scenario

$$L_T = L_R + L_E$$

Parameter	Definition	Central Tendency	High End
L_T	Total constituent load to the waterbody (g/yr)		
L_R	Runoff load from pervious surfaces (g/yr)	Calculated (see Table F-2.2.)	
L_E	Soil erosion load (g/yr)	Calculated (see Table F-2.3.)	

Description

This equation calculates the total average waterbody load from runoff and erosion loads.

Table F-2.2. Pervious Runoff Load to Waterbody

Fisher Scenario			
$$L_R \; ' \; R \; x \; (A_{BF} \; x \; C_{BF} \; \% \; A_F \; x \; C_F) \; x \; \frac{BD}{2 \; \% \; Kd_s \; x \; BD} \; x \; 0.01$$			
Parameter	**Definition**	**Central Tendency**	**High End**
L_R	Pervious surface runoff load (g/yr)		
R	Average annual surface runoff (cm/yr)	Met Specific (See Table 2-1 of Report)	
BD	Soil bulk density (g/cm^3)	1.4	
A_{BF}	Area of buffer field (m^2)	Calculated (see Table F-1.4.)	
C_{BF}	Constituent concentration in buffer field (mg/kg)	Calculated (see Table F-1.1.)	
A_F	Area of source field (m^2)	Ag field = 902,450 Home garden = 5,100	
C_F	Constituent concentration in surce field (mg/kg)	Chemical specific	
Kd_s	Soil-water partition coefficient (L/kg) or (cm^3/g)	Chemical specific (see Appendix A)	
0.01	Units conversion factor (kg-cm^2/mg-m^2)		
2	Volumetric soil water content (cm^3/cm^3)	Calculated (see Table F-1.8.)	
Description			
This equation calculates the average runoff load to the waterbody from pervious soil surfaces in the sub-basin.			

Table F-2.3. Erosion Load to Waterbody

Fisher Scenario

$$L_E = [(X_{e,F} \; x \; A_F \; x \; C_F) + (X_{e,BF} \; x \; A_{BF} \; x \; C_{BF})] \; x \; SD_{SB} \; x \; ER \; \frac{Kd_s \; x \; BD}{\theta + Kd_s \; x \; BD} \; x \; 0.001$$

Parameter	Definition	Central Tendency	High End
L_E	Constituent load via soil erosion load (g/yr)		
$X_{e,WF}$	Unit soil loss from the source field ($kg/m^2/yr$)	Calculated (see Table F-1.3.)	
A_F	Source field area (m^2)	Ag field = 902,450 Home garden = 5,100	
C_F	Source field constituent concentration (mg/kg)	Chemical specific	
$X_{e,BF}$	Unit soil loss for buffer field (kg/m^2 -yr)	Calculated (see Table F-1.11.)	
A_{BF}	Buffer field area (m^2)	Calculated (see Table F-1.4.)	
C_{BF}	Constituent concentration in the buffer field (mg/kg)	Calculated (see Table F-1.1.)	
SD_{SB}	Sediment delivery ratio for sub-basin (unitless)	Calculated (see Table F-1.5.)	
ER	Soil enrichment ratio (unitless)	Metals = 1	
Kd_s	Soil-water partition coefficient (L/kg) or (cm^3/g)	Chemical specific (see Appendix A)	
BD	Soil bulk density (g/cm^3)	1.4	
θ	Volumetric soil water content (cm^3/cm^3)	Calculated (see Table F-1.8)	
0.001	Units conversion factor (g/mg)		

Description

This equation calculates the load to the waterbody resulting from soil erosion.

Table F-2.4. Total Waterbody Concentration

Fisher Scenario

$$C_{wtot} = \frac{L_T}{Vf_x \times f_{water} + k_{wt} \times WA_w \times (d_w + d_b)}$$

Parameter	Definition	Input Value
C_{wtot}	Total water body concentration, including water column and bed sediment (mg/L) or (g/(m^3)	
L_T	Total chemical load into waterbody, including runoff and erosion (g/yr)	Calculated (see Table F-2.1.)
Vf_x	Average volumetric flow rate through water body (m^3/yr)	3×10^8
f_{water}	Fraction of total water body constituent concentration that occurs in the water column (unitless)	Calculated (see Table F-2.5.)
k_{wt}	Overall total waterbody dissipation rate constant (1/yr)	Calculated (see Table F-2.6.)
WA_w	Waterbody surface area (m^2)	1.0×10^6
d_w	Depth of water column (m)	0.64
d_b	Depth of upper benthic layer (m)	0.03

Description

This equation calculates the total waterbody concentration, including both the water column and the bed sediment.

Table F-2.5. Fraction in Water Column and Benthic Sediment

Fisher Scenario

$$f_{water} = \frac{(1 + Kd_{sw} \times TSS \times 10^{-6}) \times d_w / d_z}{(1 + Kd_{sw} \times TSS \times 10^{-6}) \times d_w / d_z + (\theta_{bs} + Kd_{bs} \times BS) \times d_b / d_z}$$

$$f_{benth} = 1 - f_{water}$$

Parameter	Definition	Central Tendency	High End
f_{water}	Fraction of total waterbody constituent concentration that occurs in the water column (unitless)		
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)	Chemical specific (see Appendix A)	
TSS	Total suspended solids (mg/L)	80	
10^{-6}	Conversion factor (kg/mg)		
d_w	Depth of the water column (m)	0.64	
d_z	Total waterbody depth (m)	Calculated (d_w+d_b)	
d_b	Depth of the upper benthic layer (m)	0.03	
θ_{bs}	Bed sediment porosity (L_{water}/L)	0.6	
Kd_{bs}	Bed sediment/sediment pore water partition coefficient (L/kg) or (g/cm^3)	Chemical-specific (see Appendix A)	
BS	Bed sediment concentration (g/cm^3)	1.0	
f_{benth}	Fraction of total waterbody constituent concentration that occurs in the benthic sediment (unitless)		

Description

These equations calculate the fraction of total waterbody concentration occurring in the water column and the bed sediments.

Table F-2.6. Overall Total Waterbody Dissipation Rate Constant

Fisher Scenario

$$k_{wt} = f_{water} \times k_v + k_b$$

Parameter	Definition	Central Tendency	High End
k_{wt}	Overall total waterbody dissipation rate constant (1/yr)		
f_{water}	Fraction of total waterbody constituent concentration that occurs in the water column	Calculated (see Table F-2.5.)	
k_v	Water column volatilization rate constant (1/yr)	Calculated (see Table F-2-7.)	
k_b	Benthic burial rate constant (1/yr)	Calculated (see Table F-2.10.)	

Description

This equation calculates the overall dissipation rate of constituent in surface water due to volatilization and benthic burial.

Table F-2.7. Water Column Volatilization Loss Rate Constant

Fisher Scenario

$$k_v = \frac{K_v}{d_z \times (1 + Kd_{sw} \times TSS \times 10^{-6})}$$

Parameter	Definition	Central Tendency	High End
k_v	Water column volatilization rate constant (1/yr)		
K_v	Overall transfer rate (m/yr)	Calculated (see Table F-2.8.)	
d_z	Total waterbody depth (m)	Calculated (d_w+d_b)	
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)	Chemical specific (see Appendix A)	
TSS	Total suspended solids (mg/L)	80	
10^{-6}	Conversion factor (kg/mg)		

Description

This equation calculates the water column constituent loss due to volatilization.

Table F-2.8. Overall Transfer Rate

Fisher Scenario			
$$K_v = \left[K_L^{-1} + \left(K_G \frac{H}{R \times T_k} \right)^{-1} \right]^{-1} \times \theta^{(T_k - 293)}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
K_v	Overall transfer rate (m/yr)		
K_L	Liquid phase transfer coefficient (m/yr)	Calculated (see Table F-2.9.)	
K_G	Gas phase transfer coefficient (m/yr) – flowing stream or river	36,500	
H	Henry's Law constant (atm-m^3/mol)	Chemical specific (see Appendix A)	
R	Universal gas constant (atm-m^3/mol-K)	8.205 x 10^{-5}	
T_k	Waterbody temperature (K)	298	
θ	Temperature correction factor (unitless)	1.026	
Description			
This equation calculates the overall transfer rate of constituent from the liquid and gas phases in surface water.			

Table F-2.9. Liquid Phase Transfer Coefficient

Fisher Scenario			
- Flowing stream or river $$K_L = \sqrt{\frac{10^{-4} \times D_w \times u}{d_z}} \times 3.15 \times 10^7$$			
Parameter	**Definition**	**Central Tendency**	**High End**
K_L	Liquid phase transfer coefficient (m/yr)		
D_w	Diffusivity of chemical in water (cm^2/s)	Chemical specific (see Appendix A)	
u	Current velocity (m/s)	0.7	
d_z	Total waterbody depth (m)	Calculated (d_w+d_b)	
$3.15x10^7$	Conversion constant (s/yr)		
10^{-4}	Units conversion factor (m^2/cm^2)		
Description			
This equation calculates the transfer rate of constituent from the liquid phase for a flowing system.			

Table F-2.10. Benthic Burial Rate Constant

Fisher Scenario

$$k_b = f_{benth} \times \left(\frac{W_b}{d_b}\right)$$

Parameter	Definition	Central Tendency	High End
k_b	Benthic burial rate constant (1/yr)		
f_{benth}	Fraction of total waterbody constituent concentration that occurs in the benthic sediment	Calculated (see Table F-2.5.)	
W_b	Burial rate (m/yr)	Calculated (see Table F-2.11.)	
d_b	Depth of upper benthic sediment layer (m)	0.03	

Description

This equation calculates the water column constituent loss due to burial in benthic sediment.

Table F-2-11. Benthic Burial Rate Constant

Fisher Scenario

$$W_b = W_{dep} \times \left(\frac{TSS \times 10^{-6}}{BS} \right)$$

Parameter	Definition	Central Tendency	High End
W_b	Benthic burial rate constant (m/yr)		
W_{dep}	Deposition rate to bottom sediment (m/yr)	Calculated (see Table F-2.12.)	
TSS	Total suspended solids (mg/L)	80	
10^{-6}	Units conversion factor (kg/mg)		
BS	Bed sediments concentration (kg/L)	1	

Description

This equation is used to determine the loss of constituent from the benthic sediment layer.

Table F-2.12. Deposition Rate to Bottom Sediment

Fisher Scenario

$$W_{dep} = \left(\frac{X_{e,SB} \ x \ A_{SB} \ x \ SD_{SB} \ x \ 1000 - Vf_x \ x \ TSS}{WA_w \ x \ TSS} \right)$$

Parameter	Definition	Central Tendency	High End
W_{dep}	Deposition rate to bottom sediment (m/yr)		
$X_{e,SB}$	Unit soil loss from the sub-basin (kg/m^2/yr)	Calculated (see Table F-2.13.)	
A_{SB}	Area of sub-basin (m^2)	Calculated (see Table F-2.24.)	
SD_{SB}	Sub-basin sediment delivery ratio (unitless)	Calculated (see Table F-1.5.)	
Vf_x	Average volumetric flow rate (m^3/yr)	3.0×10^8	
TSS	Total suspended solids (g/m^3)	80	
1000	Units conversion factor (g/kg)		
WA_w	Waterbody surface area (m^2)	1×10^6	

Description

This equation is used to determine the loss of constituent from the waterbody as it deposits onto the benthic sediment.

Table F-2.13. Universal Soil Loss Equation (USLE) for the Sub-Basin

All Exposure Scenarios

$$X_{e,SB} \; ' \; R_{SB} \; x \; K_{SB} \; x \; LS_{SB} \; x \; C_{SB} \; x \; P_{SB} \; x \; \frac{907.18}{4,047}$$

Parameter	Definition	Central Tendency	High End
$X_{e,SB}$	Unit soil loss from the sub-basin (kg/m^2-yr)		
R_{SB}	USLE rainfall factor (1/yr)	Met Specific (See Table 2-1 of Report)	
K_{SB}	USLE erodibility factor (ton/acre)	Met Specific (See Table 2-1 of Report)	
LS_{SB}	USLE length-slope factor (unitless)	1.5	
C_{SB}	USLE cover factor (unitless)	0.15	
P_{SB}	USLE erosion control practice factor (unitless)	1.0	
907.18	Units conversion factor (kg/ton)		
4,047	Units conversion factor (m^2/acre)		

Description

This equation is used to calculate the soil loss rate from the sub-basin using the Universal Soil Loss Equation.

Table F-2.14. Sub-basin Area

Fisher Scenario			
$$A_{SB} = A_F + A_{BF}$$			
Parameter	**Definition**	**Central Tendency**	**High End**
A_{SB}	Area of Sub-basin		
A_F	Area of source field of interest (m^2)	Ag. Field = 902,450 Home garden = 5,100	
A_{BF}	Area of buffer field (m^2)	Calculated (see Table F-1.4.)	
Description			
This equation is used to calculate the area of the sub-basin.			

Table F-2.15. Total Water Column Concentration

Fisher Scenario

$$C_{wt} = f_{water} \times C_{wtot} \times \frac{d_w + d_b}{d_w}$$

Parameter	Definition	Central Tendency	High End
C_{wt}	Total concentration in water column (mg/L)		
f_{water}	Fraction of total water body constituent concentration that occurs in the water column (unitless)	Calculated (see Table F-2.5.)	
C_{wtot}	Total water concentration in surface water system, including water column and bed sediment (mg/L)	Calculated (see Table F-2.4.)	
d_b	Depth of upper benthic layer (m)	0.03	
d_w	Depth of the water column (m)	0.64	

Description

This equation calculates the total water column concentration of constituent; this includes both dissolved constituent and constituent sorbed to suspended solids.

Table F-2.16. Dissolved Water Concentration

Fisher Scenario

$$C_{dw} = \frac{C_{wt}}{1 + Kd_{sw} \; x \; TSS \; x \; 10^{-6}}$$

Parameter	Definition	Central Tendency	High End
C_{dw}	Dissolved phase water concentration (mg/L)		
C_{wt}	Total concentration in water column (mg/L)	Calculated (see TableF-2.15.)	
Kd_{sw}	Suspended sediment/surface water partition coefficient (L/kg)	Chemical specific (see Appendix A)	
10^{-6}	Units conversion factor (kg/mg)		
TSS	Total suspended solids (mg/L)	80	

Description

This equation calculates the concentration of constituent dissolved in the water column.

Table F-2.17. Concentration Sorbed to Bed Sediment

Fisher Scenario

$$C_{bs} = f_{benth} \times C_{wtot} \times \frac{Kd_{bs}}{\theta_{bs} + Kd_{bs} \times BS} \times \frac{d_w + d_b}{d_b}$$

Parameter	Definition	Central Tendency	High End
C_{bs}	Concentration sorbed to bed sediments (mg/kg)		
f_{benth}	Fraction of total waterbody constituent concentration that occurs in the bed sediment (unitless)	Calculated (see Table F-2-5.)	
C_{wtot}	Total water concentration in surface water system, including water column and bed sediment (mg/L)	Calculated (see Table F-2.4.)	
d_w	Total depth of water column (m)	0.64	
d_b	Depth of the upper benthic layer (m)	0.03	
θ_{bs}	Bed sediment porosity (unitless)	0.6	
Kd_{bs}	Bed sediment/sediment pore water partition coefficient (L/kg)	Chemical specific (see Appendix A)	
BS	Bed sediment concentration (kg/L)	1.0	

Description

This equation calculates the concentration of constituent sorbed to bed sediments.

Table F-2.18. Fish Concentration from Dissolved Water Concentration

Fisher Scenario			
$C_{fish} = C_{dw} \times BCF$			
Parameter	**Definition**	**Central Tendency**	**High End**
C_{fish}	Fish concentration (mg/kg)		
C_{dw}	Dissolved water concentration (mg/L)	Calculated (see Table F-2.16.)	
BCF	Bioconcentration factor (L/kg)	Chemical specific (see Appendix A)	
Description			
This equation calculates fish concentration from dissolved water concentration using a bioconcentration factor.			

Table F-2.19. Fish Concentration from Dissolved Water Concentration

Fisher Scenario			
$$C_{fish} = C_{wt} \times BAF$$			
Parameter	**Definition**	**Central Tendency**	**High End**
C_{fish}	Fish concentration (mg/kg)		
C_{wt}	Dissolved water concentration (mg/L)	Calculated (see Table F-2.15.)	
BAF	Bioconcentration factor (L/kg)	Chemical specific (see Appendix A)	
Description			
This equation calculates fish concentration from dissolved water concentration using a bioconcentration factor.			

Table F-2.21. Fish Concentration from Bottom Sediment Concentration

Fisher Scenario

$$C_{fish} = \frac{C_{BS} \; x \; BSAF \; x \; f_{lipid}}{OC_{BS}}$$

Parameter	Definition	Central Tendency	High End
C_{fish}	Fish concentration (mg/kg)		
C_{BS}	Dissolved water concentration (mg/L)	Calculated (see Table F-2.17.)	
BSAF	Biota to sediment accumulation factor (L/kg)	Chemical specific (see Appendix A)	
f_{lipid}	Fish lipid content (fraction)	0.05	
OC_{BS}	Fraction organic carbon in bed sediment (unitless)	2.34×10^{-3}	6.88×10^{-3}

Description

This equation calculates fish concentration from bottom sediment concentration using a bioaccumulation factor.

Table F-3.1. Exposed Vegetables Concentration Due to Direct Deposition

Farmer and Home Gardener Scenarios

$$Pd = \frac{D_{dep}\ x\ D_v\ x\ 315.36)\ x\ Rp\ x\ [(1.0 - \exp(-kp\ x\ Tp)]}{Yp\ x\ kp}$$

Parameter	Definition	Central Tendency	High End
Pd	Concentration in plant due to direct deposition (mg/kg) or (µg/g)		
D_{dep}	Dry deposition of particles (g/m^2/yr)	Modeled	
315.36	Units conversion factor (mg-m-s/µg-cm-yr)		
Rp	Interception fraction of edible portion of plant (dimensionless)	0.074	
kp	Plant surface loss coefficient (1/yr)	18	
Tp	Length of plant exposure to deposition of edible portion of plant, per harvest (yrs)	0.16	
Yp	Yield or standing crop biomass of the edible portion of the plant (kg DW/m^2)	3	

Description

This equation calculates the contaminant concentration in exposed vegetation due to wet and dry deposition of contaminant on the plant surface.

Table F-3.2. Exposed Vegetables Concentration Due to Air-to-Plant Transfer

Farmer and Home Gardener Scenarios		
$$Pv = \frac{Cv \ x \ Bv \ x \ VG_{ag}}{D_a}$$		
Parameter	**Definition**	**Value**
Pv	Concentration of pollutant in the plant due to air-to-plant transfer (mg/kg) or (µg/g)	
Cv	Air concentration of vapor (µg/m^3)	Waste management scenario-specific
Bv	Air-to-plant biotransfer factor ([mg pollutant/kg plant tissue DW]/[µg pollutant/g air])	Chemical-specific (see Appendix A)
VG_{ag}	Empirical correction factor for exposed vegetables (dimensionless)	0.01
D_a	Density of air (g/cm^3)	1.2×10^{-3}
Description		
This equation calculates the contaminant concentration in exposed vegetation due to direct uptake of vapor phase contaminants into the plant leaves.		

Table F-3.3. Exposed Vegetables Concentration Due to Root Uptake

Farmer and Home Gardener Scenarios			
$Pr = Sc \times Br$			
Parameter	**Definition**	**Central Tendency**	**High End**
Pr	Concentration of pollutant in the plant due to direct uptake from soil (mg/kg)		
Sc	Average soil concentration of pollutant over exposure duration (mg/kg)	Calculated (see Table F-1.1)	
Br	Plant-soil bioconcentration factor for exposed vegetables [µg/g DW]/[µg/g soil]	Chemical-specific (see Appendix A)	
Description			
This equation calculates the contaminant concentration in exposed vegetation due to direct uptake of contaminants from soil.			

Table F-3.4. Exposed Fruit Concentration Due to Direct Deposition

Farmer and Home Gardener Scenarios

$$Pd = \frac{D_{dep}\ x\ D_v\ x\ 315.36)\ x\ Rp\ x\ [(1.0 - \exp(-kp\ x\ Tp)]}{Yp\ x\ kp}$$

Parameter	Definition	Central Tendency	High End
Pd	Concentration in plant due to direct deposition (mg/kg) or (µg/g)		
D_{dep}	Dry deposition of particles (g/m^2/yr)	Modeled	
315.36	Units conversion factor (mg-m-s/µg-cm-yr)		
Rp	Interception fraction of edible portion of plant (dimensionless)	0.01	
kp	Plant surface loss coefficient (1/yr)	18	
Tp	Length of plant exposure to deposition of edible portion of plant, per harvest (yrs)	0.16	
Yp	Yield or standing crop biomass of the edible portion of the plant (kg DW/m^2)	0.12	

Description

This equation calculates the contaminant concentration in exposed fruit due to wet and dry deposition of contaminant on the plant surface.

Table F-3.5. Exposed Fruit Concentration Due to Air-to-Plant Transfer

Farmer and Home Gardener Scenarios

$$Pv = \frac{Cv \ x \ Bv \ x \ VG_{ag}}{\rho_a}$$

Parameter	Definition	Value
Pv	Concentration of pollutant in the plant due to air-to-plant transfer (mg/kg) or (µg/g)	
Cv	Air concentration of vapor (µg/m^3)	Waste management scenario-specific
Bv	Air-to-plant biotransfer factor ([mg pollutant/kg plant tissue DW]/[µg pollutant/g air])	Chemical-specific (see Appendix A)
VG_{ag}	Empirical correction factor for exposed vegetables (dimensionless)	0.01
ρ_a	Density of air (g/cm^3)	1.2 x 10^{-3}

Description

This equation calculates the contaminant concentration in exposed fruit due to direct uptake of vapor phase contaminants into the plant leaves.

Table F-3.6. Exposed Fruit Concentration Due to Root Uptake

Farmer and Home Gardener Scenarios			
$$Pr = Sc \times Br$$			
Parameter	**Definition**	**Central Tendency**	**High End**
Pr	Concentration of pollutant in the plant due to direct uptake from soil (mg/kg)		
Sc	Average soil concentration of pollutant over exposure duration (mg/kg)	Calculated (see Table F-1.1)	
Br	Plant-soil bioconcentration factor for exposed vegetables [µg/g DW]/[µg/g soil]	Chemical-specific (see Appendix A)	
Description			
This equation calculates the contaminant concentration in exposed fruit due to direct uptake of contaminants from soil.			

Table F-3.7. Root Vegetable Concentration Due to Root Uptake

Farmer and Home Gardener Scenarios

$$Pr_{bg} = \frac{Sc \ x \ RCF}{Kd_s} \qquad (organics)$$

$$Pr_{bg} = Sc \ x \ B_r \qquad (metals)$$

Parameter	Definition	Central Tendency	High End
Pr_{bg}	Concentration of pollutant in belowground plant parts due to root uptake (mg/kg)		
Sc	Soil concentration of pollutant (mg/kg)	Calculated (see Table E-1.1)	
RCF	Ratio of concentration in roots to concentration in soil pore water ([mg pollutant/kg plant tissue FW] /[µg pollutant/mL pore water])	Chemical-specific (see Appendix A)	
B_r	Soil to plant biotransfer factor for root vegetables (µg pollutant/g plant tissue DW)/(mg pollutant/ g soil)	Chemical-specific (see Appendix A)	
Kd_s	Soil-water partition coefficient (mL/g)	Chemical-specific (see Appendix A)	

Description

This equation calculates the contaminant concentration in root vegetables due to uptake from the soil water.

Table F-4.1. Beef Concentration Due to Plant and Soil Ingestion

Farmer Scenario

$$A_{beef} = (\Sigma F \ x \ Qp_i \ x \ P_i + Qs \ x \ Sc) \ x \ Ba_{beef}$$

Parameter	Definition	Central Tendency	High End
A_{beef}	Concentration of pollutant in beef (mg/kg)		
F	Fraction of plant grown on contaminated soil and eaten by the animal (dimensionless)	1	
Qp_i	Quantity of plant eaten by the animal each day (kg plant tissue DW/day) - beef grain - beef silage - beef forage	 0.47 2.5 8.8	
P_i	Total concentration of pollutant in each plant species eaten by the animal (mg/kg) = Pd + Pv + Pr	Calculated (see Tables F-4.3, F-4.4, F-4.5)	
Qs	Quantity of soil eaten by the foraging animal (kg soil/day)	0.5	
Sc	Soil concentration (mg/kg)	Calculated (see Table E.1.1)	
Ba_{beef}	Biotransfer factor for beef (d/kg)	Chemical-specific (see Appendix A)	

Description

This equation calculates the concentration of contaminant in beef from ingestion of forage, silage, grain, and soil.

Table F-4.2. Milk Concentration Due to Plant and Soil Ingestion

Farmer Scenario

$$A_{milk} = (\Sigma F \times Qp_i \times P_i + Qs \times Sc) \times Ba_{milk}$$

Parameter	Definition	Central Tendency	High End
A_{milk}	Concentration of pollutant in milk (mg/kg)		
F	Fraction of plant grown on contaminated soil and eaten by the animal (dimensionless)	1	
Qp_i	Quantity of plant eaten by the animal each day (kg plant tissue DW/day) - grain - silage - forage	 3.0 4.1 13.2	
P_i	Total concentration of pollutant in each plant species eaten by the animal (mg/kg) = Pd + Pv + Pr	Calculated (see Tables F-4.3, F-4.4, F-4.5)	
Qs	Quantity of soil eaten by the foraging animal (kg soil/day)	0.4	
Sc	Soil concentration (mg/kg)	Calculated (see Table F-1.1)	
Ba_{milk}	Biotransfer factor for milk (day/kg)	Chemical-specific (see Appendix A)	

Description

This equation calculates the concentration of contaminant in milk from ingestion of forage, silage, grain, and soil.

Table F-4.3. Forage (Pasture Grass/Hay) Concentration Due to Direct Deposition

Farmer Scenario

$$Pd = \frac{(D_{dep})\ x\ Rp\ x\ [(1.0 - \exp(-kp\ x\ Tp)]}{Yp\ x\ kp}$$

Parameter	Definition	Central Tendency	High End
Pd	Concentration in plant due to direct deposition (mg/kg) or (µg/g)		
D_{dep}	Dry deposition of particles (g/m^2/yr	Modeled	
Rp	Interception fraction of edible portion of plant (dimensionless) - forage	0.5	
kp	Plant surface loss coefficient (1/yr)	18	
Tp	Length of the plant exposure to deposition of edible portion of plant per harvest (yrs) - forage	0.12	
Yp	Yield or standing crop biomass of the edible portion of the plant (kg DW/m^2)	0.24	
315.36	Units conversion (mg-m-s/µg-on-yr)		

Description

This equation calculates the contaminant concentration in the plant due to dry particle deposition of contaminant on the plant surface.

Table F-4.4. Forage (Pasture Grass/Hay) Concentration Due to Air-to-Plant Transfer

Farmer Scenario

$$Pv = \frac{Cv \ x \ Bv \ x \ VG_{ag}}{\rho_a}$$

Parameter	Definition	Central Tendency	High End
Pv	Concentration of pollutant in the plant due to air-to-plant transfer (mg/kg)		
Cv	Vapor phase air concentration of pollutant in air due to direct emissions (µg pollutant/m^3)	Modeled	
Bv	Air-to-plant biotransfer factor ([mg pollutant/kg plant tissue DW]/[µg [pollutant/g air])	Chemical-specific (see Appendix A)	
VG_{ag}	Empirical correction factor (dimension less)	1.0	
ρ_a	Density of air (g/cm^3)	1.2×10^{-3}	

Description

This equation calculates the contaminant concentration in the plant due to direct uptake of vapor phase contaminants into the plant leaves.

Table F-4.5. Forage/Silage/Grain Concentraton Due to Root Uptake

Farmer Scenario		
$$Pr = Sc \times Br$$		
Parameter	**Definition**	**Value**
Pr	Concentration of pollutant in the plant due to direct uptake from soil (mg/kg)	
Sc	Average soil concentration of pollutant over exposure duration (mg/kg)	Calculated (see Table F-1.1)
Br	Plant-soil bioconcentraton factor plant [µg/g DW]/[µg/g soil]	Chemical-specific (see Appendix A)
Description		
This equation calculates the contaminant concentration in the plant due to direct uptake of contaminants from soil.		

Table F-5.1. Contaminant Intake from Soil

$$I_{soil} = Sc \cdot CR_{soil} \cdot F_{soil}$$

Parameter	Description	Value
I_{soil}	Daily intake of contaminant from soil (mg/d)	
Sc	Average soil concentration of pollutant over exposure duration (mg/kg)	calculated (see Table F-1.1)
CR_{soil}	Consumption rate of soil (kg/d)	varies (See Table 5-4 of Report)
F_{soil}	Fraction of consumed soil contaminated (unitless)	(See Table 5-6 of Report)

Description

This equation calculates the daily intake of contaminant from soil consumption. The soil concentration will vary with each scenario, and the soil consumption rate varies for children and adults.

Table F-5.2. Contaminant Intake from Exposed Vegetable Intake

$$I_{ev} = (Pd + Pv + Pr) \cdot CR_{ag} \cdot F_{ag}$$

Parameter	Description	Value
I_{ag}	Daily intake of contaminant from exposed vegetables (mg/kg Fw)	
Pd	Concentration in exposed vegetables due to deposition (mg/kg Dw)	calculated (see Table F-3.1)
Pv	Concentration in exposed vegetables due to air-to-plant transfer (mg/kg Dw)	calculated (see Table F-3.2)
Pr	Concentration in exposed vegetables due to root uptake (mg/kg Dw)	calculated (see Table F-3.3)
CR_{ag}	Consumption rate of exposed vegetables (kg Dw/d)	varies (See Table 5-4 of Report)
F_{ag}	Fraction of exposed vegetables contaminated (unitless)	varies (See Table 5-6 of Report)

Description

This equation calculates the daily intake of contaminate from ingestion of exposed vegetables. The consumption rate varies for children and adults. The contaminated fraction and the concentration in exposed vegetables will vary with each scenario.

Table F-5.3. Contaminant Intake from Exposed Fruit Intake

$$I_{ef} = (Pd + Pv + Pr) \cdot CR_{ag} \cdot F_{ag}$$

Parameter	Description	Value
I_{ef}	Daily intake of contaminant from exposed fruit (mg/kg Fw)	
Pd	Concentration in exposed fruit due to deposition (mg/kg Dw)	calculated (see Table F-3.4)
Pv	Concentration in exposed fruit due to air-to-plant transfer (mg/kg Dw)	calculated (see Table F-3.5)
Pr	Concentration in exposed fruit due to root uptake (mg/kg Dw)	calculated (see Table F-3.6)
Cr_{ag}	Consumption rate of exposed fruit (kg Dw/d)	varies (See Table 5-4 of Report)
F_{ag}	Fraction of exposed fruit contaminated (unitless)	varies (See Table 5-6 of Report)

Description

This equation calculates the daily intake of contaminate from ingestion of exposed fruit. The consumption rate varies for children and adults. The contaminated fraction and the concentration in exposed fruit will vary with each scenario.

Table F-5.4. Contaminant Intake from Root Vegetable Intake

$$I_{ev} = Pr_{bg} \cdot CR_{rv} \cdot F_{rv}$$

Parameter	Description	Value
I_{rv}	Daily intake of contaminant from root vegetables for dioxins (mg/kg Fw); metals (mg/kg Dw)	
Pr_{rv}	Concentration in root vegetables due to deposition for dioxins (mg/kg Fw); metals (mg/kg Dw)	calculated (see Table F-3.7)
Cr_{rv}	Consumption rate of root vegetables for dioxins (kg Fw/d); metals (kg Dw/d)	varies (See Table 5-4 of Report)
F_{rv}	Fraction of root vegetables contaminated (unitless)	varies (See Table 5-6 of Report)

Description

This equation calculates the daily intake of contaminate from ingestion of exposed vegetables. The consumption rate varies for children and adults. The contaminated fraction and the concentration in exposed vegetables will vary with each scenario.

Table F-5.5. Contaminant Intake from Beef and Milk

$$I_i = A_i \cdot CR_i \cdot F_i$$

Parameter	Description	Value
I_i	Daily intake of contaminant from animal tissue *i* (mg/d)	
A_i	Concentration in animal tissue *i* (mg/kg Fw) - for Dioxins and (mg/kg Dw) - for Cadmium	calculated (see Table F-4.1, F-4.2)
CR_i	Consumption rate of animal tissue *i* (kg Fw/d) - for Dioxins and (Kg Dw/d) - for Cadmium	varies (See Table 5-4 of Report)
F_i	Fraction of animal tissue *i* contaminated (unitless)	varies (See Table 5-6 of Report)

Description

This equation calculates the daily intake of contaminate from ingestion of animal tissue (where the "*i*" in the above equation refers to beef and milk). The consumption rate varies for children and adults and for the type of animal tissue.

Table F-5.6. Contaminant Intake from Fish		
$$I_{fish} = C_{fish} \cdot CR_{fish} \cdot F_{fish}$$		
Parameter	**Description**	**Value**
I_{fish}	Daily intake of contaminant from fish (mg/d)	
C_{fish}	Concentration in fish (mg/kg)	calculated (see Table F-2.18)
Cr_{fish}	Consumption rate of fish (kg/d)	varies (See Table 5-4 of Report)
F_{fish}	Fraction of fish contaminated (unitless)	(See Table 5-6 of Report)
Description		
This equation calculates the daily intake of contaminate from ingestion of fish.		

Table F-5.7. Total Daily Intake

Adult and Child Home Gardener

$$I = I_{soil} + I_{ev} + I_{ef} + I_{rv}$$

Farmer

$$I = I_{soil} + I_{ev} + I_{beef} + I_{milk} + I_{ef} + I_{rv}$$

Fisher

$$I = I_{fish}$$

Parameter	Description	Value
I	Total daily intake of contaminant (mg/d)	
I_{soil}	Daily intake of contaminant from soil (mg/d)	calculated (see Appendix F-5.1)
I_{ev}	Daily intake of contaminant from exposed vegetables	calculated (see Appendix F-5.2)
I_{ef}	Daily intake of contaminant from exposed fruit (mg/d)	calculated (see Appendix F-5.3)
I_{rv}	Daily intake of contaminant from root vegetables	calculated (see Appendix F-5.4)
I_{beef}, I_{milk}	Daily intake of contaminant from animal tissue (mg/d)	calculated (see Appendix F-5.5)
I_{fish}	Daily intake of contaminant from fish (mg/d)	calculated (see Appendix F-5.6)

Description

This equation calculates the daily intake of contaminant on a pathway by pathway basis.

Table F-5.7. (Continued) Total Daily Intake

$$I = I_{soil} + I_{ev} + I_{beef} + I_{milk} + I_{fish} + I_{ef} + I_{rv}$$

Parameter	Description	Value
I	Total daily intake of contaminant (mg/d)	
I_{soil}	Daily intake of contaminant from soil (mg/d)	calculated (see Table F-5.1)
I_{ev}	Daily intake of contaminant from exposed vegetables (mg/d)	calculated (see Table F-5.2)
I_{ef}	Daily intake of contaminant from exposed fruit (mg/d)	calculated (see Table F-5.3)
I_{rv}	Daily intake of contaminant from root vegetables fruit (mg/d)	calculated (see Table F-5.4)
I_{beef}, I_{milk}	Daily intake of contaminant from animal tissue (mg/d)	calculated (see Table F-5.5)
I_{fish}	Daily intake of contaminant from fish (mg/d)	calculated (see Table F-5.6)

Description

This equation calculates the daily intake of contaminate via all indirect pathways.

Table F-5.8. Individual Cancer Risk: Carcinogens

$$Cancer\ Risk = \frac{I \cdot ED \cdot EF \cdot CSF}{BW \cdot AT \cdot 365}$$

Parameter	Description	Value
Cancer Risk	Individual lifetime cancer risk (unitless)	
I	Total daily intake of contaminant (mg/d)	calculated (see Table F-5.6)
ED	Exposure duration (yr)	varies (See Table 5-5 of Report)
EF	Exposure frequency (day/yr)	350
BW	Body weight (kg)	adult: 70 child: varies
AT	Averaging time (yr)	70
365	Units conversion factor (day/yr)	
CSF	Oral cancer slope factor (per mg/kg/d)	chemical-specific (see Appendix A)

Description

This equation calculates the individual cancer risk from indirect exposure to carcinogenic chemicals. The body weight varies for the child. The exposure duration varies for different scenarios.

Table F-5.9. Hazard Quotient: Noncarcinogens

$$HQ = \frac{I}{BW \cdot RfD}$$

Parameter	Description	Value
HQ	Hazard quotient (unitless)	
I	Total daily intake of contaminant (mg/d)	calculated (see Table F-5.6)
BW	Body weight (kg)	adult: 70 child: varies
RfD	Reference Dose (mg/kg/d)	chemical-specific (see Appendix A)

Description

This equation calculates the hazard quotient for indirect exposure to noncarcinogenic chemicals. The body weight varies for the child.

Table F-5.10 Total Cancer Risk for Farmer Scenario: Carcinogens		
$$Total\ Cancer\ Risk = \sum_i Cancer\ Risk_i$$		
Parameter	**Definition**	**Value**
Total Cancer Risk	Total individual lifetime cancer risk for all chemicals (unitless)	
Cancer $Risk_i$	Individual lifetime cancer risk for chemical carcinogen I (unitless)	calculated (see Table F-5.7)
Description		
For carcinogens, cancer risks are added across all carcinogenic chemicals.		

Table F-5.11 Hazard Index for Specific Organ Effects for Farmer Scenario: Noncarcinogens

$$HI_j = \sum_i HQ_i$$

Parameter	Definition	Value
Hi_j	Hazard index for specific organ effect j (unitless)	
HQ_i	Hazard quotient for chemical I with specific organ effect j (unitless)	calculated (see Table F-5.9)

Description

For noncancer health effects, hazard quotients are added across chemicals when they target the same organ to calculate an overall hard index.

Table F-6.1 Inhalation Cancer Risk for Individual Chemicals from Unit Risk Factor: Carcinogens

$$Cancer\ Risk = C_a \cdot URF$$

Parameter	Description	Value
Cancer Risk	Individual Lifetime cancer risk (unitless)	
C_a	Concentration in air ($\mu g/m^3$)	calculated
UFR	Inhalation Unit Risk Factor (per $\mu g/m^3$)	chemical-specific (see Appendix A)

Description

This equation calculates the inhalation cancer risk for individual constituents using the Unit Risk Factor.

Table F-6.2. Inhalation Cancer Risk for Individual Chemicals from Carcinogenic Slope Factor: Carcinogens

$$Cancer\ Risk = ADI \times CSF_{inh}$$

$$ADI = \frac{C_a \times IR \times ET \times EF \times ED \times 0.001\ mg/\mu g}{BW \times AT \times 365\ day/yr}$$

Parameter	Description	Value
Cancer Risk	Individual lifetime cancer risk (unitless)	
ADI	Average daily intake via inhalation (mg/kg/day)	
IR	Inhalation rate (m^3/hr)	Varies (See Table 5-4 of Report)
ET	Exposure time (hr/day)	24
EF	Exposure frequency (day/yr)	350
BW	Body weight (kg)	Adult = 70 Child = varies
AT	Averaging time (yr)	70
CSF_{inh}	Inhalation Carcinogenic slope Factor (per mg/kg/day)	chemical-specific (see Appendix A)

Description

This equation calculates the inhalation cancer risk for individual constituents using the Carcinogenic Slope Factor.

Table F-6.3. Inhalation Hazard Quotient for Individual Chemicals: Noncarcinogens

$$HQ = \frac{C_a \cdot 0.001 \ mg/\mu g}{RfC}$$

Parameter	Description	Value
HQ	Hazard quotient (unitless)	
C_a	Concentration in air ($\mu g/m^3$)	calculated
RfC	Reference concentration (mg/m^3)	chemical-specific (see Appendix A)

Description

This equation calculates the inhalation hazard quotient for individual constituents.

Table F-6.4 Total Inhalation Cancer Risk: Carcinogens		
$$Total\ Cancer\ Risk = \sum_i Cancer\ Risk_i$$		
Parameter	**Definition**	**Value**
Total Cancer Risk	Total individual lifetime cancer risk for all chemicals (unitless)	
Cancer $Risk_i$	Individual lifetime cancer risk for chemical carcinogen I (unitless)	calculated (see Tables F-6.1, F-6.2)
Description		
For carcinogens, cancer risks are added across all carcinogenic chemicals.		

Table F-6.5 Hazard Index for Inhalation: Noncarcinogens

$$HI_{inh} = \sum_{i} HQ_i$$

Parameter	Definition	Value
Hi_{inh}	Hazard index for inhalation (unitless)	
HQ_i	Hazard quotient for chemical I (unitless)	calculated (see Table F-6.3)

Description

For noncancer health effects, hazard quotients are added across chemicals when the same organ to calculate an overall hazard index.

Appendix G

Waste Partitioning Model Used for Agricultural Soil Amendment Scenario

Appendix G

Waste Partitioning Model

A spreadsheet calculation model was used to determine the contaminant losses from land applied FBC wastes used as agricultural soil amendment due to degradation, leaching, and rainwater runoff. The model tracks the average annual soil concentration and the annual mass of contaminant losses for the active life of the agricultural field (100 years) followed by 40 years of inactive use.

The total concentration of contaminant in the soil can be expressed as the sum of the masses of contaminant adsorbed on the soil and dissolved in the liquid divided by the total mass of contaminated soil as follows:

$$C_T = C_s + 2_w\ C_w/D_b \qquad (1)$$

where

C_T = total contaminant concentration (mg/kg = g/Mg)
C_s = concentration of contaminant adsorbed on soil (mg/kg = g/Mg)
2_w = water-filled soil porosity (m^3_{water}/m^3_{soil})
C_w = concentration of contaminant in liquid (µg/cm^3 = g/m^3)
D_b = soil dry bulk density (g/cm^3 = Mg/m^3)

The adsorbed contaminant concentration is assumed to be linearly related to the liquid phase concentration as follows:

$$C_s = K_d\ C_w \qquad (2)$$

where

K_d = soil-water partition coefficient (cm^3/g = m^3/Mg)

Equations 2 and 3 assume linear equilibrium partitioning between the adsorbed contaminant and the dissolved contaminant. Combining Equations 1 and 2 yields:

$$C_T = C_s(2_w/(K_d D_b)). \qquad (3)$$

The total contaminant concentration, C_T, represents the measured soil concentration. However, it is the adsorbed soil concentration that is used to calculate the equilibrium partitioning equations. Equation 3 can be rearranged to calculate the adsorbed soil contaminant concentration given the total contaminant concentration as follows:

$$C_s = C_T\ K_d\ D_b/(K_d\ D_b + 2_w). \qquad (4)$$

The total mass of contaminant applied to the soil during the first annual application can be calculated as follows:

$$M_{s,app} = (C_T\ Q_{app}) \times 1\text{-yr} \tag{5}$$

where

$M_{s,app}$ = mass of contaminant in soil from waste application, g
Q_{app} = annual waste application rate, Mg/yr.

Contaminant loss to the rain water runoff, or to leachate is calculated from the mass flux of contaminant across the boundaries of the land treatment unit. Contaminant loss through degradation is estimated from contaminant half-lives in soil. As all of these mechanisms compete for the removal of the contaminant, apparent first order rate constants were developed for each removal pathway based on the total soil concentration (C_T). For a given pathway, the first order rate equation is:

$$(*C_T\ /\ *t) = -\ k_{app}\ C_T \tag{6}$$

where

k_{app} = the apparent first order rate constant, 1/sec
t = time, sec.

For small time steps, Equation 6 can be solved for k_{app} as follows:

$$k_{app} = \{1 - (M_{s,t+ªt}\ / M_{s,t}\ )\}/(ªt) \tag{7}$$

where

$M_{s,t+ªt}$ = mass of contaminant in soil at time t+ªt, g
$M_{s,t}$ = mass of contaminant in soil at time t, g
ªt = time step of calculation, sec

The mass flux loss of a contaminant due to leaching is estimated by assuming the leachate is in equilibrium with the soil (i.e., Equation 2 applies).

$$J_{leach,t} = C_T\ D_b\ (0.01V_L)/(D_b\ K_d + 2_w) \tag{8}$$

where

$J_{leach,t}$ = contaminant flux in leachate at time t, g/m^2-s
V_L = (P + I - R - E)/(365 × 24 × 3600] = leachate rate (cm/sec)
P = annual average precipitation rate (cm/yr)
I = annual average irrigation rate (cm/yr)
R = annual average runoff rate (cm/yr)

The leaching flux rate can be converted to a first order rate constant as follows:

$$k_{app,leach} = (J_{leach,t})(A/M_{s,t}). \qquad (9)$$

where

A = area of contaminant source, m^2 .

The equation describing the mass flux loss of a contaminant due to runoff is nearly identical to Equation 9, because the runoff is also assumed to be in equilibrium with the contaminated soil. Consequently, the total mass rate of contaminant loss due to runoff is:

$$J_{runoff,t} = C_T\, D_b\, (0.01V_R)/(D_b\, K_d + 2_w) \qquad (10)$$

where

$J_{runoff,t}$ = contaminant run-off rate at time t, g/m^2-s

V_R = R/(365 × 24 × 3600] = runoff rate (cm/sec).

Then,

$$k_{app,runoff} = (J_{runoff,t})(A/M_{s,t}). \qquad (11)$$

First order biodegradation rates (and hydrolysis rates, if applicable) are input to the model from reported literature values or calculated from reported contaminant half-lives. The overall apparent first order disappearance rate is simply the sum of all of the individual first order rate constants.

$$k_{app,overall} = k_{app,leach} + k_{app,runoff} + k_{app,bio} + k_{app,hyd} \qquad (12)$$

The total mass lost from the system is calculated from the overall first order rate constant as follows:

$$^{a}M_{tot} = M_{s,t}\,[1 - \exp(-\, k_{app,overall}\, {^{a}t})] \qquad (13)$$

where

$^{a}M_{tot}$ = total mass of contaminant loss from the system, g.

The mass lost from the system based on any one pathway is calculated from the total mass lost from the system, the ratio of that pathway's apparent first order rate constant, and the overall first order rate constant as follows:

$$^{a}M_{pathway} = {^{a}M_{tot}}\,(k_{app,pathway} / k_{app,overall}) \qquad (14)$$

After each time interval, the mass of constituent remaining in the soil is calculated. It is assumed that the contaminant concentrations are uniform over the tilling depth at the beginning of each time interval. The model does not attempt to assess the temporal concentration profiles (as a function of depth). This assumption is reasonable for active land treatment units that are tilled regularly.

Mass additions to the system occur during waste application. The depth of material added during an application is generally negligible; however, some model scenarios could have significant waste material accumulation over 100 years depending on the tilling depth, application rate, and other factors. Consequently, the net mass of contaminant added to the agricultural field at the start of Year 1 through Year 100 is:

$$M_{s,app} = C_T\, Q_{app}\, [1 - \{(Q_{app} \times 1\text{-yr})/(A\, D_b)\}/d_{till}] \times 1\text{-yr} \tag{15}$$

where

d_{till} = tilling depth.

Appendix H

Human Health Results

Appendix H
Human Health Results

Viewing Human Health Results Tables:

- For all result tables, the first column (labeled "Parameters Set to High-end") indicates the input parameters(s) that were set to their high-end value for that particular model run.

- The first row of results is labeled "Central Tendency." This row reflects results for the model run where all input parameters are set to their central tendency value.

- The single high-end results correspond to the model runs in which only one input parameter was set at its high-end value.

- Following the single-high-end model results all double-high-end model results are presented.

- Results for the ingestion pathway are the summed results from all ingested contaminated media. For example, the ingestion result for the adult resident is the summed risk or hazard quotient for soil ingestion, fruit ingestion, below-ground vegetable ingestion, and above-ground vegetable ingestion.

- Results are presented in standard notation for non-carcinogens (e.g., 0.01) and in scientific notation (e.g., 3E-6) for carcinogens.

- All results that exceed threshold values (defined as 1.0 for non-carcinogens and 1E-6 for carcinogens) are italicized with a bold border around the cell.

- The maximum result for each constituent is bolded as well as being italicized and having a bold border.

Key to Table Numbers:

- The first set of results (all results labeled H1-*) are for ingestion pathway results.

- The second set of results (results labeled H2-*) are for the inhalation pathway.

- All H1 results are presented first and then H2 results are presented.

- The number after the dash (i.e., H1-*) refers to the waste stream/waste management unit combination (see Figure H-1 below).

- The final letter in the Table number (i.e., H1-3*) refers to the receptor (see Figure H-1 below). **Note: because the home gardener and adult resident scenarios are combined, and because inhalation is not assessed for the fisher, there are no receptors labeled**

“d” or “e” for the inhalation pathway. Also, as discussed in Section 4.4 of the report, the inhalation pathway for FBC wastes used as agricultural soil amendment was not assessed; therefore, there are no inhalation results for waste management option “7” in the chart below.

- The following chart can be used to expedite searches for specific results tables. The column titles present all possibilities for the variables within the particular part of the title name. What each of these variables stands for is presented in the cells below it.

Figure H-1. Chart for Use When Reading Results Tables

H	**1-2**	**-**	**1-7**	**a-e**
Appendix No.	1 = Ingestion pathway		1 = Utility coal, co-managed wastes onsite landfill	a = Farmer
	2 = Inhalation pathway		2 = Utility coal, co-managed waste dewatered surface impoundment	b = Child
			3 = Utility oil wastes managed in onsite landfill	c = Adult Resident
			4 = Non-utility coal co-managed wastes in onsite landfill	d = Home Gardener
			5 = Non-utility coal co-managed wastes in offsite landfill	3 = Fisher
			6 = FBC wastes managed in onsite landfill	
			7 = FBC wastes used as agricultural soil amendment	

Table H1-1a Farmer Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Waste Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.00005	0.00002	0.003	6.7E-08	0.001	1.3E-08	0.0000004	0.0007	0.00004	0.000005	0.000006
Single High-end Parameter											
Long Exposure	0.00005	0.00002	0.003	2.7E-07	0.001	5.2E-08	0.0000004	0.0007	0.00004	0.000005	0.000006
Beef intake	0.0001	0.00002	0.03	8.2E-08	0.001	2.5E-08	0.0000004	0.0007	0.0001	0.00002	0.000007
Dairy Intake	0.0001	0.00009	0.006	2.1E-07	0.002	1.3E-08	0.0000004	0.0007	0.0001	0.00001	0.00002
Exposed Veg. Intake	0.00007	0.00002	0.004	7.6E-08	0.002	2.1E-08	0.0000007	0.001	0.00004	0.000007	0.000007
Root Veg. Intake	0.00007	0.00002	0.004	7.4E-08	0.002	1.7E-08	0.0000004	0.001	0.00004	0.000005	0.000007
Fruit Intake	0.00009	0.00002	0.004	8.8E-08	0.004	3.3E-08	0.000002	0.002	0.00005	0.000009	0.000008
Waste Concentration	0.0001	0.00005	0.008	6.0E-07	0.01	2.4E-08	0.000001	0.003	0.0002	0.000007	0.0002
Adult Soil Intake	0.00005	0.00002	0.004	6.8E-08	0.001	1.7E-08	0.0000005	0.0007	0.00004	0.000006	0.000006
Meteorological Location	0.00006	0.00002	0.004	7.8E-08	0.002	1.6E-08	0.0000004	0.0008	0.00004	0.000007	0.000005
Distance to Receptor	0.00006	0.00006	0.006	1.1E-07	0.001	1.8E-08	0.000001	0.0008	0.00008	0.00001	0.00001
WMU Area	0.0002	0.00008	0.01	2.8E-07	0.006	6.0E-08	0.000001	0.003	0.0001	0.00002	0.00001
Double High-end Parameters											
Beef Intake/ Long Exposure	0.0001	0.00002	0.03	3.3E-07	0.001	1.0E-07	0.0000004	0.0007	0.0001	0.00002	0.000007
Dairy Intake/Long Exposure	0.0001	0.00009	0.006	8.5E-07	0.002	5.3E-08	0.0000004	0.0007	0.0001	0.00001	0.00002
Exposed Veg. Intake/ Long Exposure	0.00007	0.00002	0.004	3.0E-07	0.002	8.6E-08	0.0000007	0.001	0.00004	0.000007	0.000007
Root Veg. Intake/Long Exposure	0.00007	0.00002	0.004	3.0E-07	0.002	6.9E-08	0.0000004	0.001	0.00004	0.000005	0.000007
Fruit Intake/ Long Exposure	0.00009	0.00002	0.004	3.5E-07	0.004	1.3E-07	0.000002	0.002	0.00005	0.000009	0.000008
Waste Concentration/Long Exposure	0.0001	0.00005	0.008	*2.4E-06*	0.01	9.8E-08	0.000001	0.003	0.0002	0.000007	0.0002
Adult Soil Intake/Long Exposure	0.00005	0.00002	0.004	2.7E-07	0.001	7.0E-08	0.0000005	0.0007	0.00004	0.000006	0.000006
Meteorlogical Location/Long Exposure	0.00006	0.00002	0.004	3.1E-07	0.002	6.4E-08	0.0000004	0.0008	0.00004	0.000007	0.000005
Distance to Receptor/Long Exposure	0.00006	0.00006	0.006	4.6E-07	0.001	7.4E-08	0.000001	0.0008	0.00008	0.00001	0.00001
WMU Area/Long Exposure	0.0002	0.00008	0.01	*1.1E-06*	0.006	2.4E-07	0.000001	0.003	0.0001	0.00002	0.00001
Beef Intake/ Dairy Intake	0.0002	0.00009	0.03	2.3E-07	0.002	2.5E-08	0.0000004	0.0007	0.0002	0.00003	0.00002
Beef Intake/ Exposed Veg. Intake	0.0002	0.00002	0.03	9.1E-08	0.002	3.3E-08	0.0000007	0.001	0.0001	0.00003	0.000007
Beef Intake/Root Vegetable Intake	0.0002	0.00002	0.03	8.9E-08	0.002	2.9E-08	0.0000004	0.001	0.0001	0.00002	0.000007
Beef Intake/Fruit Intake	0.0002	0.00003	0.03	1.0E-07	0.004	4.5E-08	0.000002	0.002	0.0001	0.00003	0.000008
Beef Intake/ Waste Concentration	0.0004	0.00006	0.06	7.3E-07	0.02	4.7E-08	0.000001	0.003	0.0005	0.00003	0.0003
Beef Intake/Adult Soil Intake	0.0001	0.00002	0.03	8.3E-08	0.001	2.9E-08	0.0000005	0.0007	0.0001	0.00002	0.000007
Beef Intake/Meteorological Location	0.0003	0.00002	0.03	9.5E-08	0.002	3.0E-08	0.0000004	0.0008	0.0001	0.00003	0.000006
Beef Intake/Distance to Receptor	0.0003	0.00007	0.05	1.4E-07	0.002	3.8E-08	0.000001	0.0008	0.0003	0.00005	0.00001
Beef Intake/WMU Area	0.0008	0.00008	0.1	3.5E-07	0.006	1.1E-07	0.000001	0.003	0.0004	0.0001	0.00001
Dairy Intake/Exposed Vegetable Intake	0.0001	0.00009	0.007	2.2E-07	0.002	2.1E-08	0.0000007	0.001	0.0001	0.00001	0.00002
Dairy Intake/Root Vegetable Intake	0.0001	0.00009	0.007	2.2E-07	0.002	1.7E-08	0.0000004	0.001	0.0001	0.00001	0.00002
Dairy Intake/Fruit Intake	0.0002	0.00009	0.007	2.3E-07	0.004	3.3E-08	0.000002	0.002	0.0001	0.00002	0.00002
Dairy Intake/Waste Concentration	0.0003	0.0002	0.01	*1.9E-06*	0.02	2.5E-08	0.000001	0.003	0.0005	0.00001	0.0009
Dairy Intake/Adult Soil Intake	0.0001	0.00009	0.007	2.1E-07	0.002	1.8E-08	0.0000005	0.0007	0.0001	0.00001	0.00002
Dairy Intake/ Meteorological Location	0.0001	0.00008	0.008	2.4E-07	0.002	1.6E-08	0.0000004	0.0008	0.00009	0.00001	0.00002
Dairy Intake/Distance to Receptor	0.0001	0.0002	0.01	3.7E-07	0.002	1.9E-08	0.000001	0.0008	0.0002	0.00002	0.00005

Table H1-1a Farmer Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Waste Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Dairy Intake/ WMU Area	0.0005	0.0003	0.03	8.8E-07	0.008	6.0E-08	0.000001	0.003	0.0003	0.00005	0.00005
Exposed Veg. Intake/ Root Veg. Intake	0.00008	0.00002	0.004	8.3E-08	0.002	2.6E-08	0.0000007	0.002	0.00005	0.000007	0.000007
Exposed Veg. Intake/ Fruit Intake	0.0001	0.00002	0.004	9.7E-08	0.004	4.2E-08	0.000002	0.003	0.00006	0.00001	0.000008
Exposed Veg. Intake/Waste Concentration	0.0002	0.00005	0.009	6.8E-07	0.03	4.0E-08	0.000002	0.005	0.0002	0.000008	0.0003
Exposed Veg. Intake/Adult Soil Intake	0.00007	0.00002	0.004	7.7E-08	0.002	2.6E-08	0.0000007	0.001	0.00004	0.000007	0.000007
Exposed Veg. Intake/Meteorological Location	0.00009	0.00002	0.004	8.9E-08	0.003	2.6E-08	0.0000007	0.002	0.00004	0.000008	0.000006
Exposed Veg. Intake/Distance to Receptor	0.00009	0.00006	0.006	1.3E-07	0.003	3.0E-08	0.000002	0.002	0.00009	0.00001	0.00001
Exposed Veg. Intake/WMU Area	0.0003	0.00008	0.02	3.2E-07	0.01	9.8E-08	0.000002	0.007	0.0002	0.00003	0.00001
Root Veg. Intake/Fruit Intake	0.0001	0.00002	0.004	9.5E-08	0.004	3.8E-08	0.000002	0.003	0.00006	0.000009	0.000008
Root Veg. Intake/Waste Concentration	0.0002	0.00005	0.008	6.6E-07	0.02	3.2E-08	0.000001	0.005	0.0002	0.000007	0.0003
Root Veg. Intake/Adult Soil Intake	0.00007	0.00002	0.004	7.5E-08	0.002	2.2E-08	0.0000005	0.001	0.00005	0.000006	0.000007
Root Veg. Intake/Meteorological Location	0.00008	0.00002	0.004	8.7E-08	0.002	2.1E-08	0.0000004	0.001	0.00005	0.000007	0.000007
Root Veg. Intake/Distance to Receptor	0.00008	0.00006	0.006	1.2E-07	0.002	2.3E-08	0.000001	0.001	0.00009	0.00001	0.00001
Root Veg. Intake/WMU Area	0.0003	0.00008	0.02	3.2E-07	0.008	8.0E-08	0.000001	0.006	0.0002	0.00002	0.00002
Fruit Intake/Waste Concentration	0.0002	0.00006	0.01	7.9E-07	0.05	6.2E-08	0.000004	0.009	0.0002	0.00001	0.0003
Fruit Intake/Adult Soil Intake	0.00009	0.00002	0.004	9.0E-08	0.004	3.8E-08	0.000002	0.002	0.00005	0.000009	0.000008
Fruit Intake/Meteorological Location	0.0001	0.00002	0.004	1.0E-07	0.005	4.0E-08	0.000001	0.002	0.00005	0.00001	0.000007
Fruit Intake/Distance to Receptor	0.0001	0.00007	0.006	1.5E-07	0.005	5.0E-08	0.000005	0.002	0.0001	0.00001	0.00002
Fruit Intake/WMU Area	0.0004	0.00008	0.02	3.8E-07	0.02	1.5E-07	0.000005	0.01	0.0002	0.00004	0.00002
Waste Concentration/Adult Soil Intake	0.0001	0.00005	0.009	6.1E-07	0.01	3.3E-08	0.000002	0.003	0.0002	0.000007	0.0003
Waste Concentration/Meteorological Location	0.0002	0.00005	0.009	6.9E-07	0.02	3.0E-08	0.000001	0.003	0.0002	0.000007	0.0003
Waste Concentration/Distance to Receptor	0.0002	0.0001	0.01	*1.0E-06*	0.02	3.4E-08	0.000004	0.003	0.0003	0.00001	0.0008
Waste Concentration/WMU Area	0.0006	0.0002	0.03	***2.5E-06***	0.08	1.1E-07	0.000003	0.01	0.0006	0.00003	0.0009
Adult Soil Intake/Meteorological Location	0.00007	0.00002	0.004	8.0E-08	0.002	2.2E-08	0.0000006	0.0008	0.00004	0.000007	0.000005
Adult Soil Intake/Distance to Receptor	0.00007	0.00006	0.006	1.2E-07	0.001	2.4E-08	0.000001	0.0008	0.00008	0.00001	0.00001
Adult Soil Intake/WMU Area	0.0003	0.00008	0.02	2.9E-07	0.006	8.1E-08	0.000002	0.003	0.0002	0.00003	0.00001
Meteorological Location/Distance to Receptor	0.00009	0.00006	0.006	1.3E-07	0.002	2.2E-08	0.000001	0.001	0.00008	0.00001	0.00001
Meteorological Location/WMU Area	0.0003	0.00008	0.02	3.4E-07	0.008	7.4E-08	0.000001	0.004	0.0001	0.00003	0.00001
Distance to Receptor/WMU Area	0.00009	0.0001	0.01	1.9E-07	0.002	2.5E-08	0.000003	0.0008	0.0002	0.00002	0.00003

Table H1-1b Child of Farmer Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.0031	0.00004	0.21	7.9E-07	0.041	*2.4E-06*	0.00006	0.0093	0.003	0.00031	0.000076
Single High-end Parameter											
Long Exposure	0.0031	0.00004	0.21	9.9E-07	0.041	*2.7E-06*	0.00006	0.0093	0.003	0.00031	0.000076
Beef intake	0.0031	0.000042	0.22	8.0E-07	0.041	*2.4E-06*	0.00006	0.0093	0.0031	0.00031	0.000077
Dairy Intake	0.0031	0.00008	0.21	8.6E-07	0.041	*2.4E-06*	0.00006	0.0093	0.0031	0.00031	0.00008
Exposed Veg. Intake	0.0031	0.000041	0.21	8.0E-07	0.042	*2.4E-06*	0.00006	0.0098	0.003	0.00031	0.000077
Root Veg. Intake	0.0031	0.00004	0.21	7.9E-07	0.041	*2.4E-06*	0.00006	0.0094	0.003	0.00031	0.000077
Fruit Intake	0.0031	0.000043	0.21	8.1E-07	0.043	*2.4E-06*	0.000061	0.011	0.0031	0.00031	0.000078
Waste Concentration	0.0072	0.000082	0.51	*7.1E-06*	0.41	*4.4E-06*	0.0002	0.041	0.01	0.00041	0.0043
Adult Soil Intake	0.0031	0.00004	0.21	8.1E-07	0.041	*2.4E-06*	0.00006	0.0093	0.003	0.00031	0.000076
Child Soil Intake	0.0071	0.000051	0.61	*2.0E-06*	0.1	*6.0E-06*	0.0002	0.02	0.007	0.00081	0.00021
Meteorological Location	0.0031	0.000031	0.31	9.8E-07	0.041	*2.9E-06*	0.00008	0.01	0.003	0.00041	0.000096
Distance to Receptor	0.0041	0.000093	0.41	*1.4E-06*	0.061	*3.9E-06*	0.0001	0.01	0.0041	0.00052	0.00012
WMU Area	0.0062	0.0001	0.54	*1.8E-06*	0.094	*5.2E-06*	0.0001	0.022	0.0052	0.00063	0.00022
Double High-end Parameters											
Beef Intake/ Long Exposure	0.0031	0.000042	0.22	*1.0E-06*	0.041	*2.7E-06*	0.00006	0.0093	0.0031	0.00031	0.000077
Dairy Intake/Long Exposure	0.0031	0.00008	0.21	*1.1E-06*	0.041	*2.7E-06*	0.00006	0.0093	0.0031	0.00031	0.00008
Exposed Veg. Intake/ Long Exposure	0.0031	0.000041	0.21	*1.0E-06*	0.042	*2.7E-06*	0.00006	0.0098	0.003	0.00031	0.000077
Root Veg. Intake/Long Exposure	0.0031	0.00004	0.21	9.9E-07	0.041	*2.7E-06*	0.00006	0.0094	0.003	0.00031	0.000077
Fruit Intake/ Long Exposure	0.0031	0.000043	0.21	*1.0E-06*	0.043	*2.8E-06*	0.000061	0.011	0.0031	0.00031	0.000078
Waste Concentration/Long Exposure	0.0072	0.000082	0.51	*8.8E-06*	0.41	*5.1E-06*	0.0002	0.041	0.01	0.00041	0.0043
Adult Soil Intake/Long Exposure	0.0031	0.00004	0.21	*1.1E-06*	0.041	*3.2E-06*	0.00006	0.0093	0.003	0.00031	0.000076
Child Soil Intake/Long Exposure	0.0071	0.000051	0.61	*2.2E-06*	0.1	*6.4E-06*	0.0002	0.02	0.007	0.00081	0.00021
Meteorological Location/Long Exposure	0.0031	0.000031	0.31	*1.2E-06*	0.041	*3.3E-06*	0.00008	0.01	0.003	0.00041	0.000096
Distance to Receptor/Long Exposure	0.0041	0.000093	0.41	*1.7E-06*	0.061	*4.5E-06*	0.0001	0.01	0.0041	0.00052	0.00012
WMU Area/Long Exposure	0.0062	0.0001	0.54	*2.4E-06*	0.094	*6.0E-06*	0.0001	0.022	0.0052	0.00063	0.00022
Beef Intake/ Dairy Intake	0.0031	0.000082	0.22	8.6E-07	0.041	*2.4E-06*	0.00006	0.0093	0.0031	0.00032	0.000081
Beef Intake/ Exposed Veg. Intake	0.0031	0.000042	0.22	8.0E-07	0.042	*2.4E-06*	0.00006	0.0098	0.0031	0.00031	0.000077
Beef Intake/Root Vegetable Intake	0.0031	0.000042	0.22	8.0E-07	0.041	*2.4E-06*	0.00006	0.0094	0.0031	0.00031	0.000077
Beef Intake/Fruit Intake	0.0032	0.000044	0.22	8.1E-07	0.043	*2.4E-06*	0.000061	0.011	0.0031	0.00032	0.000079
Beef Intake/Waste Concentration	0.0073	0.000084	0.53	*7.1E-06*	0.41	*4.4E-06*	0.0002	0.041	0.01	0.00042	0.0043
Beef Intake/Adult Soil Intake	0.0031	0.000042	0.22	8.1E-07	0.041	*2.4E-06*	0.00006	0.0093	0.0031	0.00031	0.000077
Beef Intake/Child Soil Intake	0.0071	0.000053	0.62	*2.0E-06*	0.1	*6.0E-06*	0.0002	0.02	0.0071	0.00081	0.00021
Beef Intake/Meteorological Location	0.0031	0.000032	0.32	9.8E-07	0.041	*2.9E-06*	0.00008	0.01	0.0031	0.00042	0.000096
Beef Intake/Distance to Receptor	0.0042	0.000095	0.43	*1.4E-06*	0.061	*3.9E-06*	0.0001	0.01	0.0042	0.00053	0.00012
Beef Intake/WMU Area	0.0064	0.00011	0.58	*1.8E-06*	0.094	*5.2E-06*	0.0001	0.022	0.0052	0.00067	0.00022
Dairy Intake/Exposed Vegetable Intake	0.0031	0.000081	0.21	8.6E-07	0.042	*2.4E-06*	0.00006	0.0098	0.0031	0.00031	0.000081
Dairy Intake/Root Vegetable Intake	0.0031	0.00008	0.21	8.6E-07	0.041	*2.4E-06*	0.00006	0.0094	0.0031	0.00031	0.000081

Table H1-1b Child of Farmer Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Dairy Intake/Fruit Intake	0.0032	0.000083	0.21	8.7E-07	0.044	2.4E-06	0.000061	0.011	0.0031	0.00032	0.000082
Dairy Intake/Waste Concentration	0.0073	0.00012	0.52	7.6E-06	0.41	4.4E-06	0.0002	0.041	0.01	0.00042	0.0047
Dairy Intake/ Adult Soil Intake	0.0031	0.00008	0.21	8.7E-07	0.041	2.4E-06	0.00006	0.0093	0.0031	0.00031	0.00008
Dairy Intake/ Child Soil Intake	0.0071	0.000091	0.61	2.0E-06	0.1	6.0E-06	0.0002	0.02	0.0071	0.00081	0.00021
Dairy Intake/ Meteorological Location	0.0031	0.000071	0.31	1.1E-06	0.041	2.9E-06	0.00008	0.01	0.0031	0.00042	0.0001
Dairy Intake/Distance to Receptor	0.0041	0.00022	0.42	1.5E-06	0.061	3.9E-06	0.0001	0.01	0.0041	0.00052	0.00014
Dairy Intake/WMU Area	0.0064	0.00022	0.54	2.1E-06	0.095	5.2E-06	0.0001	0.022	0.0053	0.00065	0.00024
Exposed Veg. Intake/ Root Veg. Intake	0.0031	0.000041	0.21	8.0E-07	0.042	2.4E-06	0.00006	0.0099	0.003	0.00031	0.000077
Exposed Veg. Intake/ Fruit Intake	0.0031	0.000043	0.21	8.1E-07	0.044	2.4E-06	0.000061	0.012	0.0031	0.00031	0.000079
Exposed Veg. Intake/Waste Concentration	0.0072	0.000084	0.51	7.1E-06	0.42	4.4E-06	0.0002	0.043	0.01	0.00041	0.0043
Exposed Veg. Intake/Adult Soil Intake	0.0031	0.000041	0.21	8.1E-07	0.042	2.4E-06	0.00006	0.0098	0.003	0.00031	0.000077
Exposed Veg. Intake/Child Soil Intake	0.0071	0.000052	0.61	2.0E-06	0.1	6.0E-06	0.0002	0.021	0.007	0.00081	0.00021
Exposed Veg. Intake/Meteorological Location	0.0031	0.000032	0.31	9.8E-07	0.042	2.9E-06	0.00008	0.011	0.003	0.00041	0.000096
Exposed Veg. Intake/Distance to Receptor	0.0041	0.000094	0.41	1.4E-06	0.062	3.9E-06	0.0001	0.011	0.0041	0.00052	0.00012
Exposed Veg. Intake/WMU Area	0.0063	0.00011	0.54	1.8E-06	0.098	5.2E-06	0.0001	0.024	0.0052	0.00064	0.00022
Root Veg. Intake/Fruit Intake	0.0031	0.000043	0.21	8.1E-07	0.043	2.4E-06	0.000061	0.011	0.0031	0.00031	0.000078
Root Veg. Intake/Waste Concentration	0.0072	0.000082	0.51	7.1E-06	0.41	4.4E-06	0.0002	0.042	0.01	0.00041	0.0043
Root Veg. Intake/Adult Soil Intake	0.0031	0.00004	0.21	8.1E-07	0.041	2.4E-06	0.00006	0.0094	0.003	0.00031	0.000077
Root Veg. Intake/Child Soil Intake	0.0071	0.000051	0.61	2.0E-06	0.1	6.0E-06	0.0002	0.02	0.007	0.00081	0.00021
Root Veg. Intake/Meteorological Location	0.0031	0.000031	0.31	9.8E-07	0.041	2.9E-06	0.00008	0.01	0.003	0.00041	0.000096
Root Veg. Intake/Distance to Receptor	0.0041	0.000093	0.41	1.4E-06	0.061	3.9E-06	0.0001	0.01	0.0041	0.00052	0.00012
Root Veg. Intake/WMU Area	0.0063	0.0001	0.54	1.8E-06	0.094	5.2E-06	0.0001	0.022	0.0052	0.00063	0.00022
Fruit Intake/Waste Concentration	0.0073	0.000087	0.52	7.2E-06	0.43	4.4E-06	0.0002	0.047	0.01	0.00041	0.0044
Fruit Intake/Adult Soil Intake	0.0031	0.000043	0.21	8.3E-07	0.043	2.4E-06	0.000061	0.011	0.0031	0.00031	0.000078
Fruit Intake/Child Soil Intake	0.0071	0.000054	0.61	2.0E-06	0.1	6.1E-06	0.0002	0.022	0.0071	0.00081	0.00021
Fruit Intake/Meteorological Location	0.0031	0.000034	0.31	1.0E-06	0.044	2.9E-06	0.000081	0.012	0.0031	0.00041	0.000097
Fruit Intake/Distance to Receptor	0.0041	0.000098	0.41	1.4E-06	0.063	3.9E-06	0.0001	0.012	0.0041	0.00052	0.00012
Fruit Intake/WMU Area	0.0064	0.00011	0.54	1.9E-06	0.1	5.2E-06	0.0001	0.029	0.0052	0.00065	0.00023
Waste Concentration/ Adult Soil Intake	0.0072	0.000082	0.51	7.2E-06	0.41	4.5E-06	0.0002	0.041	0.01	0.00041	0.0043
Waste Concentration/ Child Soil Intake	0.02	0.00011	1	**1.7E-05**	**1**	1.1E-05	0.0005	0.1	0.03	0.00091	0.0093
Waste Concentration/Meteorological Location	0.0082	0.000072	0.62	8.7E-06	0.51	5.4E-06	0.0002	0.042	0.02	0.00041	0.0042
Waste Concentration/Distance to Receptor	0.01	0.00024	0.83	1.2E-05	0.61	7.3E-06	0.0003	0.062	0.021	0.00062	0.0069
Waste Concentration/WMU Area	0.021	0.00025	**1.1**	1.6E-05	**1**	9.6E-06	0.0004	0.096	0.031	0.00084	0.0079
Adult Soil Intake/Child Soil Intake	0.0071	0.000051	0.61	2.0E-06	0.1	6.1E-06	0.0002	0.02	0.007	0.00081	0.00021
Adult Soil Intake/Meteorological Location	0.0031	0.000031	0.31	1.0E-06	0.041	2.9E-06	0.00008	0.01	0.003	0.00041	0.000096
Adult Soil Intake/Distance to Receptor	0.0041	0.000093	0.41	1.4E-06	0.061	4.0E-06	0.0001	0.01	0.0041	0.00052	0.00012
Adult Soil Intake/WMU Area	0.0062	0.0001	0.54	1.8E-06	0.094	5.3E-06	0.0001	0.022	0.0052	0.00063	0.00022
Child Soil Intake/ Meteorological Location	0.0081	0.000051	0.71	2.4E-06	0.1	7.4E-06	0.0002	0.03	0.008	0.00091	0.00021
Child Soil Intake/Distance to Receptor	0.01	0.00011	1	3.3E-06	0.1	1.0E-05	0.0003	0.04	0.01	0.001	0.00032

Table H1-1b Child of Farmer Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Child Soil Intake/WMU Area	0.02	0.00013	*1*	*4.3E-06*	0.2	***1.3E-05***	0.0003	0.062	0.01	0.002	0.00042
Meteorological Location/Distance to Receptor	0.0051	0.000083	0.51	*1.7E-06*	0.061	*4.7E-06*	0.0001	0.02	0.0051	0.00062	0.00021
Meteorological Location/WMU Area	0.0074	0.0001	0.64	*2.2E-06*	0.1	*6.4E-06*	0.0002	0.032	0.0072	0.00084	0.00022
Distance to Receptor/WMU Area	0.0041	0.00023	0.43	*1.4E-06*	0.061	*3.9E-06*	0.0001	0.01	0.0042	0.00053	0.00014

Table H1-1c Adult Resident Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.00006	0.0000002	0.005	9.3E-09	0.0009	3.0E-08	0.000001	0.0002	0.00006	0.000007	0.000002
Single High-end Parameter											
Long Exposure	0.00006	0.0000002	0.005	9.2E-08	0.0009	2.9E-07	0.000001	0.0002	0.00006	0.000007	0.000002
Constituent Conc.	0.0002	0.0000005	0.01	8.3E-08	0.01	5.5E-08	0.000004	0.0009	0.0003	0.000008	0.00008
Meteorological Location	0.00008	0.0000003	0.007	1.2E-08	0.001	3.6E-08	0.000002	0.0003	0.00007	0.000008	0.000002
Distance To Receptor	0.0001	0.0000004	0.009	1.6E-08	0.001	4.9E-08	0.000003	0.0003	0.0001	0.00001	0.000003
WMU Area	0.0001	0.0000004	0.01	2.0E-08	0.002	6.5E-08	0.000003	0.0005	0.0001	0.00001	0.000004
Double High-end Parameters											
Constituent Conc./Long Exposure	0.0002	0.0000005	0.01	8.2E-07	0.01	5.4E-07	0.000004	0.0009	0.0003	0.000008	0.00008
Meteorological Location/Long Exposure	0.00008	0.0000003	0.007	1.1E-07	0.001	3.5E-07	0.000002	0.0003	0.00007	0.000008	0.000002
Distance to Receptor/Long Exposure	0.0001	0.0000004	0.009	1.6E-07	0.001	4.8E-07	0.000003	0.0003	0.0001	0.00001	0.000003
WMU Area/Long Exposure	0.0001	0.0000004	0.01	2.0E-07	0.002	6.3E-07	0.000003	0.0005	0.0001	0.00001	0.000004
Waste Concentration/ Meteorological Location	0.0002	0.0000006	0.01	1.0E-07	0.01	6.8E-08	0.000005	0.001	0.0004	0.00001	0.0001
Waste Concentration/ Distance to Receptor	0.0003	0.0000008	0.02	1.4E-07	0.01	9.2E-08	0.000007	0.001	0.0005	0.00001	0.0001
Waste Concentration/ WMU Area	0.0004	0.000001	0.03	1.8E-07	0.02	1.2E-07	0.000009	0.002	0.0006	0.00002	0.0002
Meteorological Location/Distance to Receptor	0.0001	0.0000005	0.01	2.0E-08	0.001	6.0E-08	0.000003	0.0004	0.0001	0.00001	0.000004
Meteorological Location/WMU Area	0.0002	0.0000005	0.01	2.5E-08	0.002	8.0E-08	0.000004	0.0006	0.0002	0.00002	0.000004
Distance to Receptor/WMU Area	0.0001	0.0000004	0.009	1.6E-08	0.001	4.9E-08	0.000003	0.0003	0.0001	0.00001	0.000003

Table H1-1d Home Gardener Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.00007	0.0000005	0.005	1.0E-08	0.001	3.0E-08	0.000001	0.0004	0.00006	0.000007	0.000002
Single High-end Parameter											
Long Exposure	0.00007	0.0000005	0.005	9.9E-08	0.001	3.0E-07	0.000001	0.0004	0.00006	0.000007	0.000002
Exposed Veg. Intake	0.00007	0.0000009	0.005	1.1E-08	0.002	3.2E-08	0.000001	0.0007	0.00006	0.000008	0.000002
Root Veg.Intake	0.00007	0.0000005	0.005	1.0E-08	0.001	3.0E-08	0.000001	0.0004	0.00006	0.000007	0.000002
Fruit Intake	0.00007	0.000001	0.005	1.2E-08	0.002	3.2E-08	0.000001	0.0008	0.00007	0.000008	0.000003
Constituent Conc.	0.0002	0.000001	0.01	9.0E-08	0.01	5.7E-08	0.000004	0.002	0.0003	0.000008	0.00009
Adult Soil Intake	0.0001	0.0000008	0.01	2.1E-08	0.002	6.6E-08	0.000003	0.0007	0.0001	0.00001	0.000004
Meteorological Location	0.00009	0.0000006	0.007	1.3E-08	0.001	3.7E-08	0.000002	0.0005	0.00007	0.000008	0.000002
Distance To Receptor	0.0001	0.0000008	0.009	1.7E-08	0.001	5.0E-08	0.000003	0.0005	0.0001	0.00001	0.000003
WMU Area	0.0001	0.000001	0.01	2.3E-08	0.003	6.8E-08	0.000003	0.001	0.0001	0.00001	0.000004
Double High-end Parameters											
Exposed Veg. Intake/Long Exposure	0.00007	0.0000009	0.005	1.1E-07	0.002	3.1E-07	0.000001	0.0007	0.00006	0.000008	0.000002
Root Veg. Intake/Long Exposure	0.00007	0.0000005	0.005	1.0E-07	0.001	3.0E-07	0.000001	0.0004	0.00006	0.000007	0.000002
Fruit Intake/Long Exposure	0.00007	0.000001	0.005	1.2E-07	0.002	3.2E-07	0.000001	0.0008	0.00007	0.000008	0.000003
Constituent Conc./Long Exposure	0.0002	0.000001	0.01	8.8E-07	0.01	5.5E-07	0.000004	0.002	0.0003	0.000008	0.00009
Adult Soil Intake/Long Exposure	0.0001	0.0000008	0.01	2.1E-07	0.002	6.5E-07	0.000003	0.0007	0.0001	0.00001	0.000004
Meteorological Location/Long Exposure	0.00009	0.0000006	0.007	1.2E-07	0.001	3.6E-07	0.000002	0.0005	0.00007	0.000008	0.000002
Distance to Receptor/Long Exposure	0.0001	0.0000008	0.009	1.7E-07	0.001	4.9E-07	0.000003	0.0005	0.0001	0.00001	0.000003
WMU Area/Long Exposure	0.0001	0.000001	0.01	2.3E-07	0.003	6.6E-07	0.000003	0.001	0.0001	0.00001	0.000004
Exposed Veg. Intake/Root Veg. Intake	0.00007	0.000001	0.005	1.2E-08	0.002	3.2E-08	0.000001	0.0007	0.00006	0.000008	0.000002
Exposed Veg. Intake/ Fruit Intake	0.00008	0.000002	0.005	1.4E-08	0.003	3.4E-08	0.000002	0.001	0.00007	0.000009	0.000003
Exposed Veg. Intake/Waste Concentration	0.0002	0.000002	0.01	1.0E-07	0.02	5.9E-08	0.000005	0.003	0.0003	0.000009	0.0001
Exposed Veg. Intake/Adult Soil Intake	0.0001	0.000001	0.01	2.3E-08	0.003	6.7E-08	0.000003	0.001	0.0001	0.00001	0.000004
Exposed Veg. Intake/Meteorological Location	0.00009	0.000001	0.007	1.4E-08	0.002	3.9E-08	0.000002	0.0009	0.00008	0.000009	0.000002
Exposed Veg. Intake/ Distance to Receptor	0.0001	0.000002	0.009	1.9E-08	0.002	5.2E-08	0.000004	0.0008	0.0001	0.00001	0.000004
Exposed Veg. Intake/WMU Area	0.0002	0.000003	0.01	3.0E-08	0.006	7.4E-08	0.000004	0.003	0.0001	0.00001	0.000005
Root Veg. Intake/Fruit Intake	0.00007	0.000001	0.005	1.2E-08	0.002	3.2E-08	0.000001	0.0008	0.00007	0.000008	0.000003
Root Veg. Intake/Waste Concentration	0.0002	0.000001	0.01	9.1E-08	0.01	5.7E-08	0.000004	0.002	0.0003	0.000008	0.00009
Root Veg. Intake/Adult Soil Intake	0.0001	0.0000008	0.01	2.1E-08	0.002	6.6E-08	0.000003	0.0007	0.0001	0.00001	0.000004
Root Veg. Intake/ Meteorological Location	0.00009	0.0000007	0.007	1.3E-08	0.001	3.7E-08	0.000002	0.0005	0.00007	0.000008	0.000002
Root Veg. Intake/ Distance to Receptor	0.0001	0.0000009	0.009	1.7E-08	0.001	5.0E-08	0.000003	0.0005	0.0001	0.00001	0.000003
Root Intake/WMU Area	0.0001	0.000002	0.01	2.4E-08	0.004	6.8E-08	0.000003	0.002	0.0001	0.00001	0.000005
Fruit Intake/Waste Concentration	0.0002	0.000003	0.01	1.1E-07	0.02	6.0E-08	0.000005	0.003	0.0003	0.000009	0.0001
Fruit Intake/Adult Soil Intake	0.0001	0.000001	0.01	2.3E-08	0.003	6.8E-08	0.000003	0.001	0.0001	0.00001	0.000005
Fruit Intake/ Meteorological Location	0.0001	0.000001	0.007	1.5E-08	0.002	4.0E-08	0.000002	0.001	0.00008	0.000009	0.000003
Fruit Intake/ Distance to Receptor	0.0001	0.000003	0.009	2.0E-08	0.002	5.3E-08	0.000004	0.001	0.0001	0.00001	0.000004
Fruit Intake/ WMU Area	0.0002	0.000005	0.01	3.3E-08	0.008	7.7E-08	0.000004	0.004	0.0001	0.00002	0.000006
Waste Concentration/ Adult Soil Intake	0.0004	0.000002	0.03	1.9E-07	0.02	1.2E-07	0.000009	0.003	0.0006	0.00002	0.0002
Waste Concentration/ Meteorological Location	0.0002	0.000001	0.01	1.1E-07	0.01	6.9E-08	0.000005	0.002	0.0004	0.00001	0.0001

Table H1-1d Home Gardener Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Waste Concentration/ Distance to Receptor	0.0003	0.000002	0.02	1.5E-07	0.01	9.4E-08	0.000008	0.002	0.0005	0.00001	0.0001
Waste Concentration/ WMU Area	0.0005	0.000003	0.03	2.1E-07	0.04	1.3E-07	0.00001	0.005	0.0006	0.00002	0.0002
Adult Soil Intake/ Meteorological Location	0.0002	0.0000009	0.01	2.6E-08	0.002	8.1E-08	0.000004	0.0008	0.0002	0.00002	0.000005
Adult Soil Intake/ Distance to Receptor	0.0002	0.000001	0.02	3.6E-08	0.003	1.1E-07	0.000006	0.001	0.0002	0.00003	0.000007
Adult Soil Intake/ WMU Area	0.0003	0.000002	0.03	4.7E-08	0.006	1.5E-07	0.000007	0.002	0.0003	0.00003	0.000008
Meteorological Location/Distance to Receptor	0.0001	0.000001	0.01	2.1E-08	0.001	6.1E-08	0.000003	0.0006	0.0001	0.00001	0.000004
Meteorological Location/WMU Area	0.0002	0.000002	0.01	2.9E-08	0.004	8.4E-08	0.000004	0.002	0.0002	0.00002	0.000005
Distance to Receptor/WMU Area	0.0001	0.000001	0.009	1.7E-08	0.001	5.1E-08	0.000004	0.0005	0.0001	0.00001	0.000004

Table H1-1e Fisher Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.000002	0.00006	0.0003	1.5E-09	0.000002	1.1E-09	0.00002	0.000004	0.00002	0.0000005	0.00001
Single High-end Parameter											
Long Exposure	0.000002	0.00006	0.0003	1.5E-08	0.000002	1.1E-08	0.00002	0.000004	0.00002	0.0000005	0.00001
Fish Intake	0.000002	0.00006	0.0006	1.7E-09	0.000002	1.8E-09	0.00002	0.00002	0.00002	0.0000005	0.00004
Waste Concentration	0.000004	0.0001	0.0005	1.3E-08	0.00003	2.1E-09	0.00005	0.00002	0.0001	0.0000006	0.0007
Meteorological Location	0.0000002	0.000003	0.00003	1.3E-10	0.0000009	1.5E-10	0.0000008	0.000001	0.000002	0.00000005	0.0000008
Distance to Receptor	0.000002	0.00006	0.0003	1.5E-09	0.000003	1.2E-09	0.00002	0.000005	0.00002	0.0000005	0.00002
WMU Area	0.000008	0.0003	0.001	7.4E-09	0.00001	5.6E-09	0.00008	0.00002	0.0001	0.000002	0.00007
Double High-end Parameters											
Fish Intake/Long Exposure	0.000002	0.00006	0.0006	1.6E-08	0.000002	1.7E-08	0.00002	0.00002	0.00002	0.0000005	0.00004
Waste Concentration/Long Exposure	0.000004	0.0001	0.0005	1.3E-07	0.00003	2.1E-08	0.00005	0.00002	0.0001	0.0000006	0.0007
Meteorological Location/Long Exposure	0.0000002	0.000003	0.00003	1.3E-09	0.0000009	1.5E-09	0.0000008	0.000001	0.000002	0.00000005	0.0000008
Distance to Receptor/Long Exposure	0.000002	0.00006	0.0003	1.5E-08	0.000003	1.2E-08	0.00002	0.000005	0.00002	0.0000005	0.00002
WMU Area/Long Exposure	0.000008	0.0003	0.001	7.2E-08	0.00001	5.5E-08	0.00008	0.00002	0.0001	0.000002	0.00007
Fish Intake/Waste Concentration	0.000004	0.0001	0.001	1.5E-08	0.00003	3.3E-09	0.00005	0.00007	0.0001	0.0000006	0.002
Fish Intake/Meteorological Location	0.0000002	0.000003	0.00008	1.4E-10	0.0000009	2.3E-10	0.0000008	0.000004	0.000002	0.00000005	0.000003
Fish Intake/Distance to Receptor	0.000002	0.00006	0.0007	1.7E-09	0.000003	1.9E-09	0.00002	0.00002	0.00002	0.0000005	0.00004
Fish Intake/WMU Area	0.000008	0.0003	0.003	8.2E-09	0.00001	8.6E-09	0.00008	0.00009	0.0001	0.000002	0.0003
Waste Concentration/Meteorological Location	0.0000006	0.000007	0.00007	1.1E-09	0.00001	2.8E-10	0.000002	0.000004	0.000008	0.00000006	0.00003
Waste Concentration/Distance to Receptor	0.000005	0.0001	0.0006	1.4E-08	0.00003	2.2E-09	0.00005	0.00002	0.0001	0.0000006	0.0007
Waste Concentration/WMU Area	0.00002	0.0007	0.003	6.6E-08	0.0001	1.0E-08	0.0002	0.00009	0.0005	0.000003	0.003
Meteorological Location/Distance to Receptor	0.0000003	0.000003	0.00004	1.6E-10	0.000001	2.0E-10	0.0000008	0.000001	0.000002	0.00000007	0.0000008
Meteorological Location/WMU Area	0.000001	0.00001	0.0001	6.0E-10	0.000004	7.0E-10	0.000004	0.000004	0.000008	0.0000002	0.000003
Distance to Receptor/WMU Area	0.000002	0.00006	0.0003	1.6E-09	0.000003	1.3E-09	0.00002	0.000006	0.00002	0.0000005	0.00002

Table H1-2a Farmer Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in Dewatered Surface Impoundment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.00002	0.00006	0.003	5.6E-08	0.0001	5.2E-09	0.000001	0.00005	0.00006	0.000006	0.00001
Single High-end Parameter											
Long Exposure	0.00002	0.00006	0.003	2.3E-07	0.0001	2.1E-08	0.000001	0.00005	0.00006	0.000006	0.00001
Beef intake	0.00005	0.00007	0.02	6.9E-08	0.0001	1.4E-08	0.000001	0.00005	0.0002	0.00002	0.00001
Dairy Intake	0.00004	0.0002	0.007	1.9E-07	0.0002	5.3E-09	0.000001	0.00005	0.0002	0.00001	0.00005
Exposed Veg. Intake	0.00002	0.00006	0.003	5.9E-08	0.0002	8.2E-09	0.000002	0.0001	0.00006	0.000006	0.00001
Root Veg. Intake	0.00002	0.00006	0.003	5.7E-08	0.0001	5.5E-09	0.000001	0.00008	0.00006	0.000006	0.00001
Fruit Intake	0.00002	0.00006	0.004	6.6E-08	0.0004	1.8E-08	0.000005	0.0002	0.00009	0.000007	0.00001
Waste Concentration	0.00004	0.0001	0.007	5.0E-07	0.001	9.7E-09	0.000004	0.0002	0.0003	0.000006	0.0008
Adult Soil Intake	0.00002	0.00006	0.003	5.6E-08	0.0001	5.5E-09	0.000001	0.00005	0.00006	0.000006	0.00001
Meteorological Location	0.0001	0.0002	0.01	2.4E-07	0.001	2.8E-08	0.000005	0.0007	0.0003	0.00002	0.00006
Distance to Receptor	0.00005	0.0002	0.01	1.8E-07	0.0004	1.7E-08	0.000004	0.0002	0.0002	0.00002	0.00006
WMU Area	0.00003	0.0001	0.007	1.2E-07	0.0002	1.1E-08	0.000002	0.0001	0.0001	0.00001	0.00003
Double High-end Parameters											
Beef Intake/ Long Exposure	0.00005	0.00007	0.02	2.8E-07	0.0001	5.7E-08	0.000001	0.00005	0.0002	0.00002	0.00001
Dairy Intake/Long Exposure	0.00004	0.0002	0.007	7.7E-07	0.0002	2.1E-08	0.000001	0.00005	0.0002	0.00001	0.00005
Exposed Veg. Intake/ Long Exposure	0.00002	0.00006	0.003	2.3E-07	0.0002	3.3E-08	0.000002	0.0001	0.00006	0.000006	0.00001
Root Veg. Intake/Long Exposure	0.00002	0.00006	0.003	2.3E-07	0.0001	2.2E-08	0.000001	0.00008	0.00006	0.000006	0.00001
Fruit Intake/ Long Exposure	0.00002	0.00006	0.004	2.6E-07	0.0004	7.2E-08	0.000005	0.0002	0.00009	0.000007	0.00001
Waste Concentration/Long Exposure	0.00004	0.0001	0.007	*2.0E-06*	0.001	3.9E-08	0.000004	0.0002	0.0003	0.000006	0.0008
Adult Soil Intake/Long Exposure	0.00002	0.00006	0.003	2.3E-07	0.0001	2.2E-08	0.000001	0.00005	0.00006	0.000006	0.00001
Meteorlogical Location/Long Exposure	0.0001	0.0002	0.01	9.6E-07	0.001	1.1E-07	0.000005	0.0007	0.0003	0.00002	0.00006
Distance to Receptor/Long Exposure	0.00005	0.0002	0.01	7.3E-07	0.0004	6.8E-08	0.000004	0.0002	0.0002	0.00002	0.00006
WMU Area/Long Exposure	0.00003	0.0001	0.007	4.7E-07	0.0002	4.4E-08	0.000002	0.0001	0.0001	0.00001	0.00003
Beef Intake/ Dairy Intake	0.00007	0.0002	0.03	2.1E-07	0.0002	1.4E-08	0.000001	0.00005	0.0003	0.00003	0.00005
Beef Intake/ Exposed Veg. Intake	0.00006	0.00007	0.02	7.2E-08	0.0002	1.7E-08	0.000002	0.0001	0.0002	0.00002	0.00001
Beef Intake/Root Vegetable Intake	0.00005	0.00007	0.02	7.0E-08	0.0002	1.5E-08	0.000001	0.00008	0.0002	0.00002	0.00001
Beef Intake/Fruit Intake	0.00006	0.00007	0.02	7.9E-08	0.0004	2.7E-08	0.000005	0.0002	0.0002	0.00003	0.00002
Beef Intake/ Waste Concentration	0.0001	0.0001	0.05	6.2E-07	0.001	2.7E-08	0.000004	0.0002	0.0008	0.00003	0.0008
Beef Intake/Adult Soil Intake	0.00005	0.00007	0.02	6.9E-08	0.0001	1.5E-08	0.000001	0.00005	0.0002	0.00002	0.00001
Beef Intake/Meteorological Location	0.0003	0.0002	0.1	2.9E-07	0.001	6.7E-08	0.000005	0.0007	0.0007	0.0001	0.00006
Beef Intake/Distance to Receptor	0.0001	0.0002	0.07	2.2E-07	0.0004	4.6E-08	0.000004	0.0002	0.0005	0.00008	0.00006
Beef Intake/WMU Area	0.0001	0.0001	0.05	1.4E-07	0.0002	3.0E-08	0.000002	0.0001	0.0004	0.00006	0.00004
Dairy Intake/Exposed Vegetable Intake	0.00004	0.0002	0.007	2.0E-07	0.0003	8.3E-09	0.000002	0.0001	0.0002	0.00001	0.00005
Dairy Intake/Root Vegetable Intake	0.00004	0.0002	0.007	1.9E-07	0.0002	5.6E-09	0.000001	0.00008	0.0002	0.00001	0.00005
Dairy Intake/Fruit Intake	0.00004	0.0002	0.008	2.0E-07	0.0004	1.8E-08	0.000005	0.0002	0.0003	0.00001	0.00005
Dairy Intake/Waste Concentration	0.0001	0.0005	0.01	*1.7E-06*	0.002	9.8E-09	0.000004	0.0002	0.0008	0.00001	0.002
Dairy Intake/Adult Soil Intake	0.00004	0.0002	0.007	1.9E-07	0.0002	5.6E-09	0.000001	0.00005	0.0002	0.00001	0.00005
Dairy Intake/ Meteorological Location	0.0003	0.0008	0.03	8.1E-07	0.002	2.8E-08	0.000005	0.0007	0.0007	0.00005	0.0002
Dairy Intake/Distance to Receptor	0.0001	0.0007	0.03	6.3E-07	0.0005	1.7E-08	0.000004	0.0002	0.0006	0.00004	0.0002

Table H1-2a Farmer Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in Dewatered Surface Impoundment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Dairy Intake/ WMU Area	0.00007	0.0004	0.01	4.0E-07	0.0004	1.1E-08	0.000002	0.0001	0.0003	0.00002	0.0001
Exposed Veg. Intake/ Root Veg. Intake	0.00002	0.00006	0.003	5.9E-08	0.0002	8.6E-09	0.000002	0.0001	0.00007	0.000006	0.00001
Exposed Veg. Intake/ Fruit Intake	0.00003	0.00007	0.004	6.8E-08	0.0004	2.1E-08	0.000006	0.0003	0.0001	0.000008	0.00002
Exposed Veg. Intake/Waste Concentration	0.00004	0.0001	0.007	5.2E-07	0.002	1.5E-08	0.000006	0.0004	0.0003	0.000006	0.0008
Exposed Veg. Intake/Adult Soil Intake	0.00002	0.00006	0.003	5.9E-08	0.0002	8.6E-09	0.000002	0.0001	0.00006	0.000006	0.00001
Exposed Veg. Intake/Meteorological Location	0.0001	0.0002	0.01	2.5E-07	0.002	4.4E-08	0.000008	0.001	0.0003	0.00002	0.00006
Exposed Veg. Intake/Distance to Receptor	0.00006	0.0002	0.01	1.9E-07	0.0006	2.7E-08	0.000006	0.0003	0.0002	0.00002	0.00006
Exposed Veg. Intake/WMU Area	0.00004	0.0001	0.007	1.2E-07	0.0004	1.7E-08	0.000004	0.0002	0.0002	0.00001	0.00004
Root Veg. Intake/Fruit Intake	0.00002	0.00006	0.004	6.7E-08	0.0004	1.8E-08	0.000005	0.0003	0.00009	0.000007	0.00001
Root Veg. Intake/Waste Concentration	0.00004	0.0001	0.007	5.1E-07	0.002	1.0E-08	0.000004	0.0004	0.0003	0.000006	0.0008
Root Veg. Intake/Adult Soil Intake	0.00002	0.00006	0.003	5.7E-08	0.0001	5.9E-09	0.000001	0.00008	0.00006	0.000006	0.00001
Root Veg. Intake/Meteorological Location	0.0001	0.0002	0.01	2.5E-07	0.002	3.2E-08	0.000005	0.001	0.0003	0.00002	0.00006
Root Veg. Intake/Distance to Receptor	0.00005	0.0002	0.01	1.8E-07	0.0004	1.8E-08	0.000004	0.0002	0.0002	0.00002	0.00006
Root Veg. Intake/WMU Area	0.00004	0.0001	0.007	1.2E-07	0.0003	1.2E-08	0.000002	0.0002	0.0001	0.00001	0.00003
Fruit Intake/Waste Concentration	0.00006	0.0001	0.008	5.9E-07	0.004	3.4E-08	0.00001	0.0007	0.0004	0.000007	0.0009
Fruit Intake/Adult Soil Intake	0.00002	0.00006	0.004	6.6E-08	0.0004	1.8E-08	0.000005	0.0002	0.00009	0.000007	0.00001
Fruit Intake/Meteorological Location	0.0002	0.0002	0.02	2.9E-07	0.004	8.6E-08	0.00002	0.002	0.0003	0.00003	0.00006
Fruit Intake/Distance to Receptor	0.00008	0.0002	0.01	2.1E-07	0.001	5.8E-08	0.00002	0.0006	0.0002	0.00002	0.00006
Fruit Intake/WMU Area	0.00006	0.0001	0.008	1.4E-07	0.0007	3.8E-08	0.00001	0.0004	0.0002	0.00001	0.00004
Waste Concentration/Adult Soil Intake	0.00004	0.0001	0.007	5.0E-07	0.001	1.0E-08	0.000004	0.0002	0.0003	0.000006	0.0008
Waste Concentration/Meteorological Location	0.0002	0.0005	0.02	***2.1E-06***	0.01	5.1E-08	0.00001	0.003	0.001	0.00002	0.002
Waste Concentration/Distance to Receptor	0.0001	0.0004	0.02	*1.6E-06*	0.004	3.2E-08	0.00001	0.0007	0.0009	0.00002	0.002
Waste Concentration/WMU Area	0.00009	0.0003	0.01	*1.1E-06*	0.002	2.0E-08	0.000007	0.0005	0.0006	0.00001	0.001
Adult Soil Intake/Meteorological Location	0.0001	0.0002	0.01	2.4E-07	0.001	3.2E-08	0.000005	0.0007	0.0003	0.00002	0.00006
Adult Soil Intake/Distance to Receptor	0.00005	0.0002	0.01	1.8E-07	0.0004	1.8E-08	0.000004	0.0002	0.0002	0.00002	0.00006
Adult Soil Intake/WMU Area	0.00003	0.0001	0.007	1.2E-07	0.0002	1.2E-08	0.000002	0.0001	0.0001	0.00001	0.00003
Meteorological Location/Distance to Receptor	0.0002	0.0006	0.04	7.1E-07	0.004	8.1E-08	0.00001	0.002	0.0007	0.00006	0.0002
Meteorological Location/WMU Area	0.0002	0.0004	0.02	4.8E-07	0.002	5.5E-08	0.000008	0.001	0.0004	0.00004	0.0001
Distance to Receptor/WMU Area	0.00006	0.0003	0.01	2.7E-07	0.0005	2.5E-08	0.000006	0.0002	0.0003	0.00002	0.00008

Table H1-2b Child of Farmer Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in Dewatered Surface Impoundment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.000028	0.000063	0.0077	4.9E-08	0.00015	9.7E-09	0.0000008	0.000048	0.000092	0.0000091	0.000021
Single High-end Parameter											
Long Exposure	0.000028	0.000063	0.0077	1.2E-07	0.00015	1.6E-08	0.0000008	0.000048	0.000092	0.0000091	0.000021
Beef intake	0.000038	0.000065	0.013	5.2E-08	0.00015	1.2E-08	0.0000008	0.000048	0.00013	0.000014	0.000022
Dairy Intake	0.000038	0.0002	0.0097	1.1E-07	0.00019	9.7E-09	0.0000008	0.000049	0.00014	0.000013	0.000041
Exposed Veg. Intake	0.00003	0.000063	0.0078	5.0E-08	0.00021	1.1E-08	0.0000013	0.000081	0.000096	0.0000093	0.000022
Root Veg. Intake	0.000029	0.000063	0.0077	4.9E-08	0.00016	9.7E-09	0.0000008	0.000052	0.000092	0.0000091	0.000021
Fruit Intake	0.000037	0.000065	0.0084	5.6E-08	0.00042	1.9E-08	0.0000043	0.00013	0.00012	0.000011	0.000025
Waste Concentration	0.000085	0.00011	0.014	4.4E-07	0.0016	1.8E-08	0.0000028	0.00019	0.00036	0.000011	0.00086
Adult Soil Intake	0.000028	0.000063	0.0077	4.9E-08	0.00015	9.9E-09	0.0000008	0.000048	0.000092	0.0000091	0.000021
Child Soil Intake	0.000041	0.000063	0.0091	5.2E-08	0.00026	2.0E-08	0.0000011	0.000088	0.0001	0.00001	0.000022
Meteorological Location	0.00022	0.00021	0.035	2.3E-07	0.0018	1.0E-07	0.0000054	0.00061	0.00042	0.000041	0.000067
Distance to Receptor	0.000086	0.00021	0.027	1.6E-07	0.00041	3.0E-08	0.000003	0.00015	0.00032	0.000033	0.000055
WMU Area	0.000054	0.0001	0.014	1.0E-07	0.00026	2.0E-08	0.0000016	0.0001	0.00019	0.000019	0.000033
Double High-end Parameters											
Beef Intake/ Long Exposure	0.000038	0.000065	0.013	1.3E-07	0.00015	2.1E-08	0.0000008	0.000048	0.00013	0.000014	0.000022
Dairy Intake/Long Exposure	0.000038	0.0002	0.0097	2.7E-07	0.00019	1.6E-08	0.0000008	0.000049	0.00014	0.000013	0.000041
Exposed Veg. Intake/ Long Exposure	0.00003	0.000063	0.0078	1.2E-07	0.00021	1.9E-08	0.0000013	0.000081	0.000096	0.0000093	0.000022
Root Veg. Intake/Long Exposure	0.000029	0.000063	0.0077	1.2E-07	0.00016	1.6E-08	0.0000008	0.000052	0.000092	0.0000091	0.000021
Fruit Intake/ Long Exposure	0.000037	0.000065	0.0084	1.4E-07	0.00042	3.9E-08	0.0000043	0.00013	0.00012	0.000011	0.000025
Waste Concentration/Long Exposure	0.000085	0.00011	0.014	*1.0E-06*	0.0016	2.9E-08	0.0000028	0.00019	0.00036	0.000011	0.00086
Adult Soil Intake/Long Exposure	0.000028	0.000063	0.0077	1.2E-07	0.00015	1.7E-08	0.0000008	0.000048	0.000092	0.0000091	0.000021
Child Soil Intake/Long Exposure	0.000041	0.000063	0.0091	1.2E-07	0.00026	2.6E-08	0.0000011	0.000088	0.0001	0.00001	0.000022
Meteorological Location/Long Exposure	0.00022	0.00021	0.035	5.2E-07	0.0018	1.4E-07	0.0000054	0.00061	0.00042	0.000041	0.000067
Distance to Receptor/Long Exposure	0.000086	0.00021	0.027	3.8E-07	0.00041	4.9E-08	0.000003	0.00015	0.00032	0.000033	0.000055
WMU Area/Long Exposure	0.000054	0.0001	0.014	2.5E-07	0.00026	3.2E-08	0.0000016	0.0001	0.00019	0.000019	0.000033
Beef Intake/ Dairy Intake	0.000048	0.0002	0.015	1.1E-07	0.00019	1.2E-08	0.0000008	0.000049	0.00018	0.000018	0.000042
Beef Intake/ Exposed Veg. Intake	0.00004	0.000065	0.013	5.3E-08	0.00021	1.4E-08	0.0000013	0.000081	0.00014	0.000014	0.000022
Beef Intake/Root Vegetable Intake	0.000039	0.000065	0.013	5.2E-08	0.00016	1.2E-08	0.0000008	0.000052	0.00013	0.000014	0.000022
Beef Intake/Fruit Intake	0.000047	0.000067	0.013	5.9E-08	0.00042	2.1E-08	0.0000043	0.00013	0.00016	0.000016	0.000025
Beef Intake/Waste Concentration	0.00012	0.00011	0.034	4.6E-07	0.0016	2.2E-08	0.0000028	0.0002	0.00056	0.000025	0.0009
Beef Intake/Adult Soil Intake	0.000038	0.000065	0.013	5.2E-08	0.00015	1.2E-08	0.0000008	0.000048	0.00013	0.000014	0.000022
Beef Intake/Child Soil Intake	0.000051	0.000065	0.014	5.5E-08	0.00026	2.2E-08	0.0000011	0.000088	0.00014	0.000015	0.000022
Beef Intake/Meteorological Location	0.00026	0.00021	0.065	2.4E-07	0.0018	1.1E-07	0.0000054	0.00062	0.00062	0.000071	0.000069
Beef Intake/Distance to Receptor	0.00013	0.00021	0.047	1.7E-07	0.00041	3.7E-08	0.000003	0.00015	0.00043	0.000053	0.000057
Beef Intake/WMU Area	0.000084	0.00011	0.034	1.1E-07	0.00026	2.4E-08	0.0000016	0.0001	0.00023	0.000039	0.000034
Dairy Intake/Exposed Vegetable Intake	0.00004	0.0002	0.0098	1.1E-07	0.00025	1.1E-08	0.0000013	0.000082	0.00015	0.000013	0.000042
Dairy Intake/Root Vegetable Intake	0.000039	0.0002	0.0097	1.1E-07	0.0002	9.7E-09	0.0000008	0.000052	0.00014	0.000013	0.000041
Dairy Intake/Fruit Intake	0.000047	0.00021	0.01	1.2E-07	0.00046	1.9E-08	0.0000043	0.00013	0.00017	0.000015	0.000045

Table H1-2b Child of Farmer Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in Dewatered Surface Impoundment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Dairy Intake/Waste Concentration	0.00012	0.00031	0.019	9.8E-07	0.0019	1.8E-08	0.0000028	0.0002	0.00076	0.000016	0.0021
Dairy Intake/ Adult Soil Intake	0.000038	0.0002	0.0097	1.1E-07	0.00019	9.9E-09	0.0000008	0.000049	0.00014	0.000013	0.000041
Dairy Intake/ Child Soil Intake	0.000051	0.0002	0.011	1.1E-07	0.0003	2.0E-08	0.0000011	0.000089	0.00015	0.000014	0.000042
Dairy Intake/ Meteorological Location	0.00027	0.00061	0.039	4.8E-07	0.0021	1.0E-07	0.0000054	0.00062	0.00062	0.000061	0.00011
Dairy Intake/Distance to Receptor	0.00014	0.00051	0.032	3.6E-07	0.00054	3.0E-08	0.000003	0.00015	0.00052	0.000043	0.00011
Dairy Intake/WMU Area	0.000084	0.0003	0.019	2.3E-07	0.00031	2.0E-08	0.0000016	0.0001	0.00029	0.000033	0.000083
Exposed Veg. Intake/ Root Veg. Intake	0.00003	0.000063	0.0078	5.0E-08	0.00022	1.1E-08	0.0000013	0.000085	0.000096	0.0000093	0.000022
Exposed Veg. Intake/ Fruit Intake	0.000039	0.000066	0.0085	5.7E-08	0.00048	2.1E-08	0.0000048	0.00016	0.00012	0.000011	0.000025
Exposed Veg. Intake/Waste Concentration	0.00009	0.00011	0.015	4.5E-07	0.0023	2.1E-08	0.0000045	0.00036	0.00038	0.000012	0.00088
Exposed Veg. Intake/Adult Soil Intake	0.00003	0.000063	0.0078	5.0E-08	0.00021	1.1E-08	0.0000013	0.000081	0.000096	0.0000093	0.000022
Exposed Veg. Intake/Child Soil Intake	0.000043	0.000063	0.0092	5.3E-08	0.00032	2.1E-08	0.0000016	0.00012	0.00011	0.000011	0.000022
Exposed Veg. Intake/Meteorological Location	0.00024	0.00021	0.035	2.3E-07	0.0025	1.1E-07	0.000007	0.0011	0.00044	0.000043	0.000069
Exposed Veg. Intake/Distance to Receptor	0.000092	0.00021	0.028	1.6E-07	0.00057	3.4E-08	0.0000046	0.00023	0.00034	0.000034	0.000057
Exposed Veg. Intake/WMU Area	0.000058	0.0001	0.015	1.0E-07	0.00043	2.3E-08	0.0000024	0.00017	0.0002	0.000019	0.000033
Root Veg. Intake/Fruit Intake	0.000038	0.000065	0.0084	5.6E-08	0.00043	1.9E-08	0.0000043	0.00013	0.00012	0.000011	0.000025
Root Veg. Intake/Waste Concentration	0.000085	0.00011	0.014	4.4E-07	0.0017	1.8E-08	0.0000028	0.00021	0.00036	0.000011	0.00086
Root Veg. Intake/Adult Soil Intake	0.000029	0.000063	0.0077	4.9E-08	0.00016	9.9E-09	0.0000008	0.000052	0.000092	0.0000091	0.000021
Root Veg. Intake/Child Soil Intake	0.000042	0.000063	0.0091	5.2E-08	0.00027	2.0E-08	0.0000011	0.000092	0.0001	0.00001	0.000022
Root Veg. Intake/Meteorological Location	0.00022	0.00021	0.035	2.3E-07	0.0019	1.0E-07	0.0000054	0.00066	0.00043	0.000041	0.000068
Root Veg. Intake/Distance to Receptor	0.000087	0.00021	0.027	1.6E-07	0.00042	3.0E-08	0.000003	0.00016	0.00032	0.000033	0.000055
Root Veg. Intake/WMU Area	0.000054	0.0001	0.014	1.0E-07	0.00026	2.0E-08	0.0000016	0.00011	0.00019	0.000019	0.000033
Fruit Intake/Waste Concentration	0.00011	0.00011	0.016	5.0E-07	0.0043	3.6E-08	0.000011	0.00072	0.00054	0.000013	0.001
Fruit Intake/Adult Soil Intake	0.000037	0.000065	0.0084	5.6E-08	0.00042	1.9E-08	0.0000043	0.00013	0.00012	0.000011	0.000025
Fruit Intake/Child Soil Intake	0.00005	0.000065	0.0098	5.9E-08	0.00053	2.9E-08	0.0000046	0.00017	0.00013	0.000012	0.000025
Fruit Intake/Meteorological Location	0.00028	0.00022	0.037	2.6E-07	0.0044	1.5E-07	0.000023	0.0024	0.0005	0.000048	0.000075
Fruit Intake/Distance to Receptor	0.00012	0.00022	0.03	1.8E-07	0.001	6.0E-08	0.000011	0.00049	0.00041	0.000038	0.000063
Fruit Intake/WMU Area	0.000071	0.00011	0.016	1.2E-07	0.00069	3.9E-08	0.0000096	0.00036	0.00025	0.000022	0.00004
Waste Concentration/ Adult Soil Intake	0.000085	0.00011	0.014	4.4E-07	0.0016	1.8E-08	0.0000028	0.00019	0.00036	0.000011	0.00086
Waste Concentration/ Child Soil Intake	0.00012	0.00011	0.016	4.6E-07	0.0027	3.7E-08	0.0000033	0.0003	0.00041	0.000013	0.00088
Waste Concentration/Meteorological Location	0.00053	0.00052	0.081	***2.0E-06***	0.018	1.9E-07	0.000014	0.0024	0.002	0.000061	0.0033
Waste Concentration/Distance to Receptor	0.00022	0.00051	0.055	*1.4E-06*	0.0043	5.5E-08	0.000008	0.0006	0.0015	0.000034	0.0022
Waste Concentration/WMU Area	0.00015	0.00031	0.031	9.1E-07	0.0036	3.6E-08	0.0000047	0.00047	0.00092	0.000021	0.0021
Adult Soil Intake/Child Soil Intake	0.000041	0.000063	0.0091	5.2E-08	0.00026	2.0E-08	0.0000011	0.000088	0.0001	0.00001	0.000022
Adult Soil Intake/Meteorological Location	0.00022	0.00021	0.035	2.3E-07	0.0018	1.0E-07	0.0000054	0.00061	0.00042	0.000041	0.000067
Adult Soil Intake/Distance to Receptor	0.000086	0.00021	0.027	1.6E-07	0.00041	3.0E-08	0.000003	0.00015	0.00032	0.000033	0.000055
Adult Soil Intake/WMU Area	0.000054	0.0001	0.014	1.0E-07	0.00026	2.0E-08	0.0000016	0.0001	0.00019	0.000019	0.000033
Child Soil Intake/ Meteorological Location	0.00042	0.00021	0.047	2.7E-07	0.0038	2.4E-07	0.0000094	0.0011	0.00062	0.000061	0.000072
Child Soil Intake/Distance to Receptor	0.00012	0.00021	0.03	1.7E-07	0.00071	5.9E-08	0.0000034	0.00028	0.00036	0.000037	0.000056
Child Soil Intake/WMU Area	0.000084	0.0001	0.016	1.1E-07	0.00056	3.9E-08	0.0000022	0.00016	0.00021	0.000021	0.000033

Table H1-2b Child of Farmer Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in Dewatered Surface Impoundment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Meteorological Location/Distance to Receptor	0.00074	0.00073	0.11	6.6E-07	0.0041	2.8E-07	0.000015	0.0017	0.0012	0.00013	0.00022
Meteorological Location/WMU Area	0.00043	0.00051	0.071	4.5E-07	0.0035	1.9E-07	0.0000098	0.0012	0.00074	0.000083	0.00011
Distance to Receptor/WMU Area	0.00014	0.00031	0.031	2.3E-07	0.00057	4.3E-08	0.0000043	0.00021	0.00035	0.000035	0.000086

Table H1-2c Adult Resident Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in Dewatered Surface Impoundment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.0000002	0.0000000006	0.00001	2.6E-11	0.000002	8.0E-11	0.000000004	0.0000006	0.0000002	0.00000002	0.000000005
Single High-end Parameter											
Long Exposure	0.0000002	0.0000000006	0.00001	2.6E-10	0.000002	7.8E-10	0.000000004	0.0000006	0.0000002	0.00000002	0.000000005
Constituent Conc.	0.0000004	0.000000001	0.00003	2.4E-10	0.00002	1.5E-10	0.00000001	0.000002	0.0000008	0.00000002	0.0000002
Adult Soil Intake	0.0000004	0.000000001	0.00003	5.8E-11	0.000004	1.8E-10	0.000000009	0.000001	0.0000004	0.00000004	0.00000001
Meteorological Location	0.000002	0.000000009	0.0002	3.7E-10	0.00003	1.1E-09	0.00000006	0.000007	0.000002	0.0000003	0.00000007
Distance To Receptor	0.0000005	0.000000002	0.00004	8.2E-11	0.000005	2.4E-10	0.00000001	0.000002	0.0000005	0.00000006	0.00000002
WMU Area	0.0000003	0.000000001	0.00003	5.4E-11	0.000004	1.6E-10	0.000000009	0.000001	0.0000004	0.00000004	0.00000001
Double High-end Parameters											
Constituent Conc./Long Exposure	0.0000004	0.000000001	0.00003	2.3E-09	0.00002	1.5E-09	0.00000001	0.000002	0.0000008	0.00000002	0.0000002
Adult Soil Intake/Long Exposure	0.0000004	0.000000001	0.00003	5.7E-10	0.000004	1.7E-09	0.000000009	0.000001	0.0000004	0.00000004	0.00000001
Meteorological Location/Long Exposure	0.000002	0.000000009	0.0002	3.6E-09	0.00003	1.1E-08	0.00000006	0.000007	0.000002	0.0000003	0.00000007
Distance to Receptor/Long Exposure	0.0000005	0.000000002	0.00004	8.0E-10	0.000005	2.3E-09	0.00000001	0.000002	0.0000005	0.00000006	0.00000002
WMU Area/Long Exposure	0.0000003	0.000000001	0.00003	5.3E-10	0.000004	1.5E-09	0.000000009	0.000001	0.0000004	0.00000004	0.00000001
Waste Concentration/ Adult Soil Intake	0.000001	0.000000003	0.00007	5.2E-10	0.00005	3.3E-10	0.00000003	0.000005	0.000002	0.00000005	0.0000005
Waste Concentration/ Meteorological Location	0.000006	0.00000002	0.0004	3.3E-09	0.0003	2.0E-09	0.0000002	0.00003	0.00001	0.0000003	0.000003
Waste Concentration/ Distance to Receptor	0.000001	0.000000004	0.00009	7.3E-10	0.00005	4.4E-10	0.00000004	0.000006	0.000003	0.00000007	0.0000008
Waste Concentration/ WMU Area	0.0000008	0.000000003	0.00006	4.8E-10	0.00004	2.9E-10	0.00000003	0.000004	0.000002	0.00000005	0.0000005
Adult Soil Intake/ Meteorological Location	0.000005	0.00000002	0.0004	8.1E-10	0.00006	2.4E-09	0.0000001	0.00002	0.000005	0.0000006	0.0000002
Adult Soil Intake/ Distance to Receptor	0.000001	0.000000004	0.00009	1.8E-10	0.00001	5.2E-10	0.00000003	0.000003	0.000001	0.0000001	0.00000004
Adult Soil Intake/ WMU Area	0.0000007	0.000000003	0.00006	1.2E-10	0.000008	3.5E-10	0.00000002	0.000002	0.0000008	0.00000008	0.00000002
Meteorological Location/Distance to Receptor	0.000006	0.00000003	0.0005	1.0E-09	0.00006	3.0E-09	0.0000002	0.00002	0.000007	0.0000007	0.0000002
Meteorological Location/WMU Area	0.000004	0.00000002	0.0004	7.1E-10	0.00004	2.0E-09	0.0000001	0.00001	0.000005	0.0000005	0.0000001
Distance to Receptor/WMU Area	0.0000007	0.000000003	0.00006	1.2E-10	0.000007	3.5E-10	0.00000002	0.000002	0.0000008	0.00000008	0.00000002

Table H1-2d Home Gardener Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in Dewatered Surface Impoundment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.000001	0.0000003	0.00006	3.1E-10	0.00002	4.4E-10	0.0000003	0.00001	0.000003	0.0000002	0.0000003
Single High-end Parameter											
Long Exposure	0.000001	0.0000003	0.00006	3.0E-09	0.00002	4.3E-09	0.0000003	0.00001	0.000003	0.0000002	0.0000003
Exposed Veg. Intake	0.000003	0.0000006	0.0001	6.8E-10	0.00006	9.1E-10	0.0000006	0.00004	0.000005	0.0000003	0.0000006
Root Veg.Intake	0.000001	0.0000003	0.00006	3.2E-10	0.00002	4.5E-10	0.0000003	0.00002	0.000003	0.0000002	0.0000003
Fruit Intake	0.000004	0.000001	0.0003	1.3E-09	0.00009	1.7E-09	0.000001	0.00006	0.00001	0.0000006	0.000001
Constituent Conc.	0.000003	0.0000005	0.0002	2.7E-09	0.0003	8.3E-10	0.0000009	0.00005	0.00001	0.0000002	0.00001
Adult Soil Intake	0.000001	0.0000003	0.00008	3.4E-10	0.00002	5.4E-10	0.0000003	0.00001	0.000003	0.0000002	0.0000003
Meteorological Location	0.000008	0.000001	0.0005	1.9E-09	0.0003	2.8E-09	0.000001	0.0002	0.00001	0.000001	0.000001
Distance To Receptor	0.000003	0.0000008	0.0002	9.9E-10	0.00007	1.4E-09	0.000001	0.00003	0.000009	0.0000005	0.0000009
WMU Area	0.000002	0.0000005	0.0002	6.4E-10	0.00006	9.2E-10	0.0000007	0.00003	0.000005	0.0000003	0.0000005
Double High-end Parameters											
Exposed Veg. Intake/Long Exposure	0.000003	0.0000006	0.0001	6.6E-09	0.00006	8.9E-09	0.0000006	0.00004	0.000005	0.0000003	0.0000006
Root Veg. Intake/Long Exposure	0.000001	0.0000003	0.00006	3.1E-09	0.00002	4.4E-09	0.0000003	0.00002	0.000003	0.0000002	0.0000003
Fruit Intake/Long Exposure	0.000004	0.000001	0.0003	1.2E-08	0.00009	1.7E-08	0.000001	0.00006	0.00001	0.0000006	0.000001
Constituent Conc./Long Exposure	0.000003	0.0000005	0.0002	2.7E-08	0.0003	8.1E-09	0.0000009	0.00005	0.00001	0.0000002	0.00001
Adult Soil Intake/Long Exposure	0.000001	0.0000003	0.00008	3.3E-09	0.00002	5.3E-09	0.0000003	0.00001	0.000003	0.0000002	0.0000003
Meteorological Location/Long Exposure	0.000008	0.000001	0.0005	1.9E-08	0.0003	2.8E-08	0.000001	0.0002	0.00001	0.000001	0.000001
Distance to Receptor/Long Exposure	0.000003	0.0000008	0.0002	9.7E-09	0.00007	1.4E-08	0.000001	0.00003	0.000009	0.0000005	0.0000009
WMU Area/Long Exposure	0.000002	0.0000005	0.0002	6.3E-09	0.00006	9.0E-09	0.0000007	0.00003	0.000005	0.0000003	0.0000005
Exposed Veg. Intake/Root Veg. Intake	0.000003	0.0000006	0.0001	6.9E-10	0.00006	9.1E-10	0.0000006	0.00004	0.000005	0.0000003	0.0000006
Exposed Veg. Intake/ Fruit Intake	0.000006	0.000001	0.0004	1.6E-09	0.0001	2.2E-09	0.000001	0.00008	0.00001	0.0000007	0.000001
Exposed Veg. Intake/Waste Concentration	0.000006	0.000001	0.0003	6.0E-09	0.0008	1.7E-09	0.000002	0.0001	0.00003	0.0000004	0.00003
Exposed Veg. Intake/Adult Soil Intake	0.000003	0.0000006	0.0002	7.1E-10	0.00006	1.0E-09	0.0000006	0.00004	0.000005	0.0000003	0.0000006
Exposed Veg. Intake/Meteorological Location	0.00002	0.000003	0.0008	4.2E-09	0.0008	5.4E-09	0.000003	0.0005	0.00002	0.000002	0.000002
Exposed Veg. Intake/ Distance to Receptor	0.000008	0.000002	0.0004	2.2E-09	0.0001	2.9E-09	0.000002	0.0001	0.00002	0.000001	0.000002
Exposed Veg. Intake/WMU Area	0.000004	0.000001	0.0003	1.4E-09	0.0001	1.9E-09	0.000001	0.00008	0.00001	0.0000006	0.000001
Root Veg. Intake/Fruit Intake	0.000004	0.000001	0.0003	1.3E-09	0.00009	1.7E-09	0.000001	0.00006	0.00001	0.0000006	0.000001
Root Veg. Intake/Waste Concentration	0.000003	0.0000005	0.0002	2.8E-09	0.0003	8.4E-10	0.0000009	0.00006	0.00001	0.0000002	0.00001
Root Veg. Intake/Adult Soil Intake	0.000001	0.0000003	0.00008	3.5E-10	0.00002	5.4E-10	0.0000003	0.00002	0.000003	0.0000002	0.0000003
Root Veg. Intake/ Meteorological Location	0.000009	0.000001	0.0005	2.0E-09	0.0004	2.9E-09	0.000001	0.0002	0.00001	0.000001	0.000001
Root Veg. Intake/ Distance to Receptor	0.000004	0.0000008	0.0002	1.0E-09	0.00007	1.4E-09	0.000001	0.00004	0.000009	0.0000005	0.0000009
Root Intake/WMU Area	0.000002	0.0000005	0.0002	6.6E-10	0.00006	9.3E-10	0.0000007	0.00004	0.000006	0.0000003	0.0000005
Fruit Intake/Waste Concentration	0.00001	0.000002	0.0006	1.1E-08	0.001	3.2E-09	0.000004	0.0002	0.00005	0.0000008	0.00006
Fruit Intake/Adult Soil Intake	0.000005	0.000001	0.0003	1.3E-09	0.00009	1.8E-09	0.000001	0.00006	0.00001	0.0000006	0.000001
Fruit Intake/ Meteorological Location	0.00002	0.000004	0.001	6.8E-09	0.001	8.6E-09	0.000005	0.0007	0.00004	0.000004	0.000004
Fruit Intake/ Distance to Receptor	0.00001	0.000004	0.0009	4.1E-09	0.0002	5.5E-09	0.000004	0.0001	0.00003	0.000002	0.000004
Fruit Intake/ WMU Area	0.000008	0.000002	0.0006	2.7E-09	0.0002	3.6E-09	0.000003	0.0001	0.00002	0.000001	0.000002
Waste Concentration/ Adult Soil Intake	0.000004	0.0000005	0.0002	3.0E-09	0.0003	1.0E-09	0.0000009	0.00006	0.00001	0.0000002	0.00001
Waste Concentration/ Meteorological Location	0.00002	0.000003	0.0009	1.7E-08	0.003	5.3E-09	0.000003	0.0008	0.00005	0.000001	0.00005
Waste Concentration/ Distance to Receptor	0.000008	0.000001	0.0005	8.8E-09	0.0008	2.6E-09	0.000003	0.0002	0.00004	0.0000006	0.00004

Table H1-2d Home Gardener Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in Dewatered Surface Impoundment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Waste Concentration/ WMU Area	0.000005	0.000001	0.0003	5.7E-09	0.0006	1.7E-09	0.000001	0.0001	0.00003	0.0000003	0.00003
Adult Soil Intake/ Meteorological Location	0.00001	0.000001	0.0007	2.3E-09	0.0004	4.2E-09	0.000001	0.0002	0.00001	0.000001	0.000001
Adult Soil Intake/ Distance to Receptor	0.000004	0.0000008	0.0002	1.1E-09	0.00007	1.7E-09	0.000001	0.00003	0.000009	0.0000005	0.0000009
Adult Soil Intake/ WMU Area	0.000002	0.0000005	0.0002	7.0E-10	0.00006	1.1E-09	0.0000007	0.00003	0.000006	0.0000004	0.0000005
Meteorological Location/Distance to Receptor	0.00002	0.000003	0.001	5.6E-09	0.0008	8.1E-09	0.000004	0.0005	0.00003	0.000002	0.000003
Meteorological Location/WMU Area	0.00002	0.000003	0.0009	3.8E-09	0.0006	5.5E-09	0.000003	0.0003	0.00002	0.000002	0.000003
Distance to Receptor/WMU Area	0.000005	0.000001	0.0003	1.4E-09	0.0001	2.1E-09	0.000001	0.00006	0.00001	0.0000008	0.000001

Table H1-2e Fisher Individual Risk from All Ingestion Pathways for Utility Coal Co-managed Wastes Managed in Dewatered Surface Impoundment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.0000001	0.00000007	0.00002	6.2E-11	0.0000004	9.1E-11	0.00000008	0.0000006	0.0000006	0.00000003	0.0000001
Single High-end Parameter											
Long Exposure	0.0000001	0.00000007	0.00002	6.1E-10	0.0000004	8.9E-10	0.00000008	0.0000006	0.0000006	0.00000003	0.0000001
Fish Intake	0.0000001	0.00000007	0.00005	6.9E-11	0.0000004	1.4E-10	0.00000008	0.000002	0.0000006	0.00000003	0.0000003
Waste Concentration	0.0000004	0.0000001	0.00004	5.5E-10	0.000004	1.7E-10	0.0000002	0.000002	0.000003	0.00000004	0.000005
Meteorological Location	0.0000005	0.0000002	0.00007	2.0E-10	0.000002	3.1E-10	0.0000003	0.000002	0.000002	0.0000001	0.0000003
Distance to Receptor	0.0000005	0.0000002	0.00006	1.9E-10	0.000001	2.8E-10	0.0000003	0.000002	0.000002	0.00000009	0.0000003
WMU Area	0.0000003	0.0000001	0.00004	1.4E-10	0.0000009	2.0E-10	0.0000002	0.000001	0.000001	0.00000006	0.0000003
Double High-end Parameters											
Fish Intake/Long Exposure	0.0000001	0.00000007	0.00005	6.7E-10	0.0000004	1.4E-09	0.00000008	0.000002	0.0000006	0.00000003	0.0000003
Waste Concentration/Long Exposure	0.0000004	0.0000001	0.00004	5.4E-09	0.000004	1.7E-09	0.0000002	0.000002	0.000003	0.00000004	0.000005
Meteorological Location/Long Exposure	0.0000005	0.0000002	0.00007	2.0E-09	0.000002	3.0E-09	0.0000003	0.000002	0.000002	0.0000001	0.0000003
Distance to Receptor/Long Exposure	0.0000005	0.0000002	0.00006	1.9E-09	0.000001	2.8E-09	0.0000003	0.000002	0.000002	0.00000009	0.0000003
WMU Area/Long Exposure	0.0000003	0.0000001	0.00004	1.3E-09	0.0000009	2.0E-09	0.0000002	0.000001	0.000001	0.00000006	0.0000003
Fish Intake/Waste Concentration	0.0000004	0.0000001	0.0001	6.1E-10	0.000004	2.6E-10	0.0000002	0.000009	0.000003	0.00000004	0.00001
Fish Intake/Meteorological Location	0.0000005	0.0000002	0.0002	2.2E-10	0.000002	4.7E-10	0.0000003	0.000008	0.000002	0.0000001	0.0000009
Fish Intake/Distance to Receptor	0.0000005	0.0000002	0.0001	2.1E-10	0.000001	4.4E-10	0.0000003	0.000007	0.000002	0.00000009	0.0000009
Fish Intake/WMU Area	0.0000003	0.0000001	0.0001	1.5E-10	0.0000009	3.1E-10	0.0000002	0.000005	0.000001	0.00000006	0.0000007
Waste Concentration/Meteorological Location	0.000001	0.0000005	0.0001	1.8E-09	0.00002	5.8E-10	0.0000008	0.000008	0.00001	0.0000001	0.00002
Waste Concentration/Distance to Receptor	0.000001	0.0000004	0.0001	1.7E-09	0.00001	5.3E-10	0.0000008	0.000007	0.000009	0.0000001	0.00002
Waste Concentration/WMU Area	0.0000008	0.0000003	0.0001	1.2E-09	0.00001	3.7E-10	0.0000005	0.000005	0.000007	0.00000008	0.00001
Meteorological Location/Distance to Receptor	0.000001	0.0000006	0.0002	5.9E-10	0.000005	9.0E-10	0.0000008	0.000006	0.000006	0.0000003	0.000001
Meteorological Location/WMU Area	0.000001	0.0000004	0.0001	4.1E-10	0.000004	6.3E-10	0.0000005	0.000004	0.000004	0.0000002	0.0000007
Distance to Receptor/WMU Area	0.0000007	0.0000003	0.00009	2.8E-10	0.000002	4.2E-10	0.0000004	0.000002	0.000003	0.0000001	0.0000005

Table H1-3a Farmer Individual Risk from All Ingestion Pathways for Utility Oil Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Arsenic	Barium	Boron	Cadmium	Chromium VI	Cobalt	Copper	Vanadium	Zinc
Central Tendency	0.0003	0.0000009	3.5E-09	0.00001	0.00000004	0.00002	0.00001	0.0000004	0.00002	0.001	0.000001
Single High-end Parameter											
Long Exposure	0.0003	0.0000009	1.4E-08	0.00001	0.00000004	0.00002	0.00001	0.0000004	0.00002	0.001	0.000001
Beef intake	0.0009	0.000001	4.3E-09	0.00002	0.00000004	0.00002	0.00004	0.000002	0.00004	0.002	0.000001
Dairy Intake	0.0007	0.000003	1.2E-08	0.00002	0.00000004	0.00002	0.00004	0.000001	0.00003	0.003	0.000001
Exposed Veg. Intake	0.0003	0.000001	3.9E-09	0.00003	0.00000006	0.00003	0.00002	0.0000005	0.00004	0.001	0.000003
Root Veg. Intake	0.0003	0.0000009	3.8E-09	0.00002	0.00000004	0.00003	0.00002	0.0000004	0.00006	0.001	0.000002
Fruit Intake	0.0005	0.000001	4.5E-09	0.00005	0.0000002	0.00006	0.00002	0.0000006	0.00006	0.002	0.000005
Waste Concentration	0.0009	0.000003	1.9E-07	0.00006	0.00000004	0.0001	0.00005	0.0000004	0.0003	0.003	0.000007
Adult Soil Intake	0.0003	0.0000009	3.6E-09	0.00001	0.00000004	0.00002	0.00002	0.0000004	0.00002	0.001	0.000001
Meteorological Location	0.0004	0.0000007	3.6E-09	0.00002	0.00000003	0.00002	0.00001	0.0000004	0.00003	0.001	0.000002
Distance to Receptor	0.0006	0.000006	1.4E-08	0.00002	0.0000003	0.00002	0.00008	0.000002	0.00004	0.006	0.000002
Double High-end Parameters											
Beef Intake/ Long Exposure	0.0009	0.000001	1.7E-08	0.00002	0.00000004	0.00002	0.00004	0.000002	0.00004	0.002	0.000001
Dairy Intake/Long Exposure	0.0007	0.000003	4.6E-08	0.00002	0.00000004	0.00002	0.00004	0.000001	0.00003	0.003	0.000001
Exposed Veg. Intake/ Long Exposure	0.0003	0.000001	1.6E-08	0.00003	0.00000006	0.00003	0.00002	0.0000005	0.00004	0.001	0.000003
Root Veg. Intake/Long Exposure	0.0003	0.0000009	1.5E-08	0.00002	0.00000004	0.00003	0.00002	0.0000004	0.00006	0.001	0.000002
Fruit Intake/ Long Exposure	0.0005	0.000001	1.8E-08	0.00005	0.0000002	0.00006	0.00002	0.0000006	0.00006	0.002	0.000005
Waste Concentration/Long Exposure	0.0009	0.000003	7.6E-07	0.00006	0.00000004	0.0001	0.00005	0.0000004	0.0003	0.003	0.000007
Adult Soil Intake/Long Exposure	0.0003	0.0000009	1.4E-08	0.00001	0.00000004	0.00002	0.00002	0.0000004	0.00002	0.001	0.000001
Meteorlogical Location/Long Exposure	0.0004	0.0000007	1.4E-08	0.00002	0.00000003	0.00002	0.00001	0.0000004	0.00003	0.001	0.000002
Distance to Receptor/Long Exposure	0.0006	0.000006	5.5E-08	0.00002	0.0000003	0.00002	0.00008	0.000002	0.00004	0.006	0.000002
Beef Intake/ Dairy Intake	0.001	0.000003	1.2E-08	0.00002	0.00000004	0.00002	0.00006	0.000003	0.00005	0.004	0.000001
Beef Intake/ Exposed Veg. Intake	0.001	0.000001	4.7E-09	0.00003	0.00000006	0.00003	0.00004	0.000002	0.00006	0.002	0.000003
Beef Intake/Root Vegetable Intake	0.001	0.000001	4.6E-09	0.00002	0.00000004	0.00003	0.00004	0.000002	0.00008	0.002	0.000002
Beef Intake/Fruit Intake	0.001	0.000001	5.3E-09	0.00005	0.0000002	0.00006	0.00005	0.000003	0.00007	0.003	0.000005
Beef Intake/ Waste Concentration	0.003	0.000003	2.3E-07	0.00006	0.00000004	0.0001	0.0001	0.000002	0.0005	0.006	0.000007
Beef Intake/Adult Soil Intake	0.0009	0.000001	4.4E-09	0.00002	0.00000004	0.00002	0.00004	0.000002	0.00004	0.002	0.000001
Beef Intake/Meteorological Location	0.001	0.0000008	4.4E-09	0.00002	0.00000003	0.00002	0.00004	0.000002	0.00004	0.002	0.000002
Beef Intake/Distance to Receptor	0.002	0.000007	1.7E-08	0.00002	0.0000003	0.00002	0.0003	0.000009	0.0001	0.01	0.000002
Dairy Intake/Exposed Vegetable Intake	0.0007	0.000003	1.2E-08	0.00004	0.00000006	0.00003	0.00004	0.000001	0.00005	0.004	0.000003
Dairy Intake/Root Vegetable Intake	0.0007	0.000003	1.2E-08	0.00002	0.00000004	0.00003	0.00004	0.000001	0.00006	0.004	0.000002
Dairy Intake/Fruit Intake	0.0009	0.000003	1.2E-08	0.00005	0.0000002	0.00006	0.00004	0.000001	0.00006	0.004	0.000005
Dairy Intake/Waste Concentration	0.001	0.00001	6.2E-07	0.00008	0.00000004	0.0001	0.0001	0.000001	0.0003	0.008	0.000007
Dairy Intake/Adult Soil Intake	0.0007	0.000003	1.2E-08	0.00002	0.00000004	0.00002	0.00004	0.000001	0.00003	0.003	0.000001
Dairy Intake/ Meteorological Location	0.0008	0.000002	1.1E-08	0.00002	0.00000003	0.00002	0.00004	0.000001	0.00003	0.003	0.000002
Dairy Intake/Distance to Receptor	0.001	0.00002	4.6E-08	0.00003	0.0000003	0.00002	0.0002	0.000005	0.00008	0.02	0.000002
Exposed Veg. Intake/ Root Veg. Intake	0.0004	0.000001	4.2E-09	0.00004	0.00000006	0.00004	0.00002	0.0000005	0.00007	0.002	0.000004
Exposed Veg. Intake/ Fruit Intake	0.0006	0.000001	4.9E-09	0.00006	0.0000002	0.00007	0.00002	0.0000007	0.00007	0.002	0.000006
Exposed Veg. Intake/Waste Concentration	0.001	0.000003	2.1E-07	0.0001	0.00000006	0.0002	0.00005	0.0000005	0.0004	0.003	0.00001

Table H1-3a Farmer Individual Risk from All Ingestion Pathways for Utility Oil Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Arsenic	Barium	Boron	Cadmium	Chromium VI	Cobalt	Copper	Vanadium	Zinc
Exposed Veg. Intake/Adult Soil Intake	0.0004	0.000001	4.0E-09	0.00003	0.00000007	0.00003	0.00002	0.0000005	0.00004	0.002	0.000003
Exposed Veg. Intake/Meteorological Location	0.0005	0.0000008	4.0E-09	0.00003	0.00000004	0.00004	0.00002	0.0000005	0.00004	0.001	0.000003
Exposed Veg. Intake/Distance to Receptor	0.0008	0.000006	1.5E-08	0.00004	0.0000004	0.00004	0.00009	0.000002	0.00006	0.007	0.000004
Root Veg. Intake/Fruit Intake	0.0006	0.000001	4.8E-09	0.00005	0.0000002	0.00007	0.00002	0.0000006	0.00009	0.002	0.000005
Root Veg. Intake/Waste Concentration	0.001	0.000003	2.1E-07	0.00007	0.00000004	0.0002	0.00005	0.0000004	0.0006	0.003	0.00001
Root Veg. Intake/Adult Soil Intake	0.0004	0.0000009	3.9E-09	0.00002	0.00000004	0.00003	0.00002	0.0000004	0.00006	0.002	0.000002
Root Veg. Intake/Meteorological Location	0.0005	0.0000008	3.9E-09	0.00002	0.00000003	0.00004	0.00002	0.0000004	0.00007	0.001	0.000003
Root Veg. Intake/Distance to Receptor	0.0007	0.000006	1.4E-08	0.00003	0.0000003	0.00004	0.00009	0.000002	0.00008	0.007	0.000004
Fruit Intake/Waste Concentration	0.001	0.000003	2.4E-07	0.0002	0.0000002	0.0004	0.00007	0.0000006	0.0006	0.004	0.00002
Fruit Intake/Adult Soil Intake	0.0005	0.000001	4.6E-09	0.00005	0.0000002	0.00006	0.00002	0.0000007	0.00006	0.002	0.000005
Fruit Intake/Meteorological Location	0.0006	0.0000008	4.7E-09	0.00005	0.0000001	0.00007	0.00002	0.0000007	0.00007	0.002	0.000006
Fruit Intake/Distance to Receptor	0.001	0.000006	1.7E-08	0.00006	0.000001	0.00008	0.0001	0.000002	0.00009	0.009	0.000008
Waste Concentration/Adult Soil Intake	0.0009	0.000003	1.9E-07	0.00006	0.00000004	0.0001	0.00005	0.0000004	0.0003	0.003	0.000007
Waste Concentration/Meteorological Location	0.001	0.000002	2.0E-07	0.00008	0.00000003	0.0001	0.00004	0.0000004	0.0003	0.003	0.000008
Waste Concentration/Distance to Receptor	0.002	0.00002	7.9E-07	0.00009	0.0000003	0.0002	0.0003	0.000002	0.0006	0.01	0.00001
Adult Soil Intake/Meteorological Location	0.0004	0.0000007	3.6E-09	0.00002	0.00000003	0.00002	0.00002	0.0000005	0.00003	0.001	0.000002
Adult Soil Intake/Distance to Receptor	0.0006	0.000006	1.4E-08	0.00002	0.0000003	0.00002	0.00008	0.000002	0.00004	0.006	0.000002
Meteorological Location/Distance to Receptor	0.0008	0.000004	1.3E-08	0.00003	0.0000002	0.00004	0.00007	0.000002	0.00006	0.005	0.000004

Table H1-3b Child of Farmer Individual Risk for All Ingestion Pathways from Utility Oil Co-Managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Arsenic	Barium	Boron	Cadmium	Chromium VI	Cobalt	Copper	Vanadium	Zinc
Central Tendency	0.02	0.0000012	3.8E-08	0.00051	0.000004	0.00031	0.00082	0.000021	0.00022	0.1	0.000031
Single High-end Parameter											
Long Exposure	0.02	0.0000012	4.8E-08	0.00051	0.000004	0.00031	0.00082	0.000021	0.00022	0.1	0.000031
Beef intake	0.021	0.0000013	3.8E-08	0.00051	0.000004	0.00031	0.00083	0.000021	0.00022	0.1	0.000031
Dairy Intake	0.021	0.0000022	4.2E-08	0.00051	0.000004	0.00031	0.00083	0.000021	0.00022	0.1	0.000031
Exposed Veg. Intake	0.021	0.0000013	3.8E-08	0.00052	0.000004	0.00032	0.00082	0.000021	0.00022	0.1	0.000032
Root Veg. Intake	0.02	0.0000012	3.8E-08	0.00051	0.000004	0.00031	0.00082	0.000021	0.00022	0.1	0.000031
Fruit Intake	0.021	0.0000013	3.9E-08	0.00053	0.0000041	0.00035	0.00083	0.000021	0.00024	0.1	0.000034
Waste Concentration	0.051	0.0000038	$\boxed{\textit{2.2E-06}}$	0.002	0.000004	0.002	0.0021	0.000021	0.0022	0.3	0.0002
Adult Soil Intake	0.02	0.0000012	3.9E-08	0.00051	0.000004	0.00031	0.00082	0.000021	0.00022	0.1	0.000031
Child Soil Intake	0.04	0.0000015	9.3E-08	0.001	0.000009	0.00081	0.002	0.000061	0.00052	0.3	0.000091
Meteorological Location	0.02	0.000001	4.6E-08	0.00061	0.000004	0.00031	0.001	0.000031	0.00021	0.1	0.000041
Distance to Receptor	0.031	0.0000067	8.2E-08	0.00091	0.0000071	0.00051	0.0021	0.000043	0.00045	0.21	0.000071
Double High-end Parameters											
Beef Intake/ Long Exposure	0.021	0.0000013	4.8E-08	0.00051	0.000004	0.00031	0.00083	0.000021	0.00022	0.1	0.000031
Dairy Intake/Long Exposure	0.021	0.0000022	5.7E-08	0.00051	0.000004	0.00031	0.00083	0.000021	0.00022	0.1	0.000031
Exposed Veg. Intake/ Long Exposure	0.021	0.0000013	4.8E-08	0.00052	0.000004	0.00032	0.00082	0.000021	0.00022	0.1	0.000032
Root Veg. Intake/Long Exposure	0.02	0.0000012	4.8E-08	0.00051	0.000004	0.00031	0.00082	0.000021	0.00022	0.1	0.000031
Fruit Intake/ Long Exposure	0.021	0.0000013	5.0E-08	0.00053	0.0000041	0.00035	0.00083	0.000021	0.00024	0.1	0.000034
Waste Concentration/Long Exposure	0.051	0.0000038	$\boxed{\textit{2.7E-06}}$	0.002	0.000004	0.002	0.0021	0.000021	0.0022	0.3	0.0002
Adult Soil Intake/Long Exposure	0.02	0.0000012	5.5E-08	0.00051	0.000004	0.00031	0.00082	0.000021	0.00022	0.1	0.000031
Child Soil Intake/Long Exposure	0.04	0.0000015	1.0E-07	0.001	0.000009	0.00081	0.002	0.000061	0.00052	0.3	0.000091
Meteorological Location/Long Exposure	0.02	0.000001	5.8E-08	0.00061	0.000004	0.00031	0.001	0.000031	0.00021	0.1	0.000041
Distance to Receptor/Long Exposure	0.031	0.0000067	1.1E-07	0.00091	0.0000071	0.00051	0.0021	0.000043	0.00045	0.21	0.000071
Beef Intake/ Dairy Intake	0.021	0.0000023	4.2E-08	0.00051	0.000004	0.00031	0.00084	0.000022	0.00023	0.1	0.000031
Beef Intake/ Exposed Veg. Intake	0.021	0.0000013	3.8E-08	0.00052	0.000004	0.00032	0.00083	0.000021	0.00023	0.1	0.000032
Beef Intake/Root Vegetable Intake	0.021	0.0000013	3.8E-08	0.00051	0.000004	0.00031	0.00083	0.000021	0.00023	0.1	0.000031
Beef Intake/Fruit Intake	0.021	0.0000013	3.9E-08	0.00053	0.0000041	0.00035	0.00084	0.000022	0.00025	0.1	0.000034
Beef Intake/Waste Concentration	0.052	0.0000039	$\boxed{\textit{2.2E-06}}$	0.002	0.000004	0.002	0.0021	0.000021	0.0022	0.3	0.0002
Beef Intake/Adult Soil Intake	0.021	0.0000013	3.9E-08	0.00051	0.000004	0.00031	0.00083	0.000021	0.00022	0.1	0.000031
Beef Intake/Child Soil Intake	0.041	0.0000016	9.4E-08	0.001	0.000009	0.00081	0.002	0.000061	0.00052	0.3	0.000091
Beef Intake/Meteorological Location	0.021	0.0000011	4.7E-08	0.00061	0.000004	0.00031	0.001	0.000031	0.00022	0.1	0.000041
Beef Intake/Distance to Receptor	0.031	0.0000069	8.3E-08	0.00091	0.0000071	0.00051	0.0022	0.000046	0.00047	0.21	0.000071
Dairy Intake/Exposed Vegetable Intake	0.021	0.0000023	4.2E-08	0.00052	0.000004	0.00032	0.00083	0.000021	0.00023	0.1	0.000032
Dairy Intake/Root Vegetable Intake	0.021	0.0000022	4.2E-08	0.00051	0.000004	0.00031	0.00083	0.000021	0.00022	0.1	0.000031
Dairy Intake/Fruit Intake	0.021	0.0000023	4.2E-08	0.00054	0.0000041	0.00035	0.00084	0.000021	0.00025	0.1	0.000034
Dairy Intake/Waste Concentration	0.052	0.0000088	$\boxed{\textit{2.4E-06}}$	0.002	0.000004	0.002	0.0021	0.000021	0.0022	0.31	0.0002
Dairy Intake/ Adult Soil Intake	0.021	0.0000022	4.2E-08	0.00051	0.000004	0.00031	0.00083	0.000021	0.00022	0.1	0.000031
Dairy Intake/ Child Soil Intake	0.041	0.0000025	9.7E-08	0.001	0.000009	0.00081	0.002	0.000061	0.00052	0.3	0.000091
Dairy Intake/ Meteorological Location	0.021	0.0000022	5.0E-08	0.00061	0.000004	0.00031	0.001	0.000031	0.00022	0.1	0.000041

Table H1-3b Child of Farmer Individual Risk for All Ingestion Pathways from Utility Oil Co-Managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Arsenic	Barium	Boron	Cadmium	Chromium VI	Cobalt	Copper	Vanadium	Zinc
Dairy Intake/Distance to Receptor	0.031	0.000021	9.7E-08	0.00092	0.0000071	0.00051	0.0022	0.000045	0.00047	0.21	0.000071
Exposed Veg. Intake/ Root Veg. Intake	0.021	0.0000013	3.8E-08	0.00052	0.000004	0.00032	0.00082	0.000021	0.00023	0.1	0.000032
Exposed Veg. Intake/ Fruit Intake	0.021	0.0000013	3.9E-08	0.00054	0.0000041	0.00036	0.00083	0.000021	0.00025	0.1	0.000035
Exposed Veg. Intake/Waste Concentration	0.051	0.0000039	*2.2E-06*	0.0021	0.000004	0.0021	0.0021	0.000021	0.0022	0.3	0.00021
Exposed Veg. Intake/Adult Soil Intake	0.021	0.0000013	3.9E-08	0.00052	0.000004	0.00032	0.00082	0.000021	0.00022	0.1	0.000032
Exposed Veg. Intake/Child Soil Intake	0.041	0.0000016	9.4E-08	0.001	0.000009	0.00082	0.002	0.000061	0.00052	0.3	0.000092
Exposed Veg. Intake/Meteorological Location	0.021	0.000001	4.7E-08	0.00062	0.000004	0.00033	0.001	0.000031	0.00022	0.1	0.000042
Exposed Veg. Intake/Distance to Receptor	0.031	0.0000067	8.3E-08	0.00093	0.0000073	0.00053	0.0021	0.000043	0.00047	0.21	0.000073
Root Veg. Intake/Fruit Intake	0.021	0.0000013	3.9E-08	0.00053	0.0000041	0.00036	0.00083	0.000021	0.00025	0.1	0.000034
Root Veg. Intake/Waste Concentration	0.051	0.0000038	*2.2E-06*	0.002	0.000004	0.002	0.0021	0.000021	0.0022	0.3	0.0002
Root Veg. Intake/Adult Soil Intake	0.02	0.0000012	3.9E-08	0.00051	0.000004	0.00031	0.00082	0.000021	0.00022	0.1	0.000031
Root Veg. Intake/Child Soil Intake	0.04	0.0000015	9.3E-08	0.001	0.000009	0.00081	0.002	0.000061	0.00052	0.3	0.000091
Root Veg. Intake/Meteorological Location	0.02	0.000001	4.7E-08	0.00061	0.000004	0.00031	0.001	0.000031	0.00022	0.1	0.000041
Root Veg. Intake/Distance to Receptor	0.031	0.0000067	8.2E-08	0.00091	0.0000071	0.00051	0.0021	0.000043	0.00046	0.21	0.000071
Fruit Intake/Waste Concentration	0.052	0.0000041	*2.2E-06*	0.0021	0.0000041	0.0023	0.0021	0.000021	0.0025	0.3	0.00022
Fruit Intake/Adult Soil Intake	0.021	0.0000013	4.0E-08	0.00053	0.0000041	0.00035	0.00083	0.000021	0.00024	0.1	0.000034
Fruit Intake/Child Soil Intake	0.041	0.0000016	9.4E-08	0.001	0.0000091	0.00085	0.002	0.000061	0.00054	0.3	0.000094
Fruit Intake/Meteorological Location	0.021	0.0000011	4.7E-08	0.00065	0.0000041	0.00036	0.001	0.000031	0.00025	0.1	0.000045
Fruit Intake/Distance to Receptor	0.031	0.000007	8.4E-08	0.00096	0.000008	0.00056	0.0022	0.000044	0.00049	0.21	0.000076
Waste Concentration/ Adult Soil Intake	0.051	0.0000038	*2.2E-06*	0.002	0.000004	0.002	0.0021	0.000021	0.0022	0.3	0.0002
Waste Concentration/ Child Soil Intake	0.1	0.0000051	***5.3E-06***	0.005	0.000009	0.005	0.0061	0.000061	0.0062	0.7	0.0004
Waste Concentration/Meteorological Location	0.061	0.000004	*2.7E-06*	0.002	0.000004	0.0021	0.0031	0.000031	0.0032	0.3	0.0002
Waste Concentration/Distance to Receptor	0.092	0.000023	*4.7E-06*	0.003	0.0000071	0.0031	0.0053	0.000043	0.0055	0.51	0.00031
Adult Soil Intake/Child Soil Intake	0.04	0.0000015	9.4E-08	0.001	0.000009	0.00081	0.002	0.000061	0.00052	0.3	0.000091
Adult Soil Intake/Meteorological Location	0.02	0.000001	4.8E-08	0.00061	0.000004	0.00031	0.001	0.000031	0.00021	0.1	0.000041
Adult Soil Intake/Distance to Receptor	0.031	0.0000067	8.4E-08	0.00091	0.0000071	0.00051	0.0021	0.000043	0.00045	0.21	0.000071
Child Soil Intake/ Meteorological Location	0.05	0.0000014	1.2E-07	0.001	0.00001	0.00091	0.003	0.000071	0.00061	0.4	0.0001
Child Soil Intake/Distance to Receptor	0.081	0.0000073	1.9E-07	0.002	0.00002	0.001	0.0041	0.0001	0.0011	0.61	0.0002
Meteorological Location/Distance to Receptor	0.041	0.0000057	9.9E-08	0.00092	0.0000091	0.00062	0.0021	0.000053	0.00054	0.31	0.000082

Table H1-3c Adult Resident Individual Risk from All Ingestion Pathways for Utility Oil C-Managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Arsenic	Barium	Boron	Cadmium	Chromium VI	Cobalt	Copper	Vanadium	Zinc
Central Tendency	0.0004	0.000000005	4.4E-10	0.00001	0.00000008	0.000007	0.00002	0.0000005	0.000004	0.003	0.0000008
Single High-end Parameter											
Long Exposure	0.0004	0.000000005	4.4E-09	0.00001	0.00000008	0.000007	0.00002	0.0000005	0.000004	0.003	0.0000008
Constituent Conc.	0.001	0.00000002	2.5E-08	0.00005	0.00000008	0.00004	0.00005	0.0000005	0.00006	0.006	0.000004
Adult Soil Intake	0.0008	0.00000001	9.8E-10	0.00003	0.0000002	0.00001	0.00004	0.000001	0.00001	0.006	0.000002
Meteorological Location	0.0005	0.000000006	5.5E-10	0.00001	0.0000001	0.000008	0.00002	0.0000006	0.000006	0.003	0.000001
Distance To Receptor	0.0007	0.00000001	9.0E-10	0.00002	0.0000002	0.00001	0.00004	0.000001	0.000009	0.005	0.000002
Double High-end Parameters											
Constituent Conc./Long Exposure	0.001	0.00000002	2.5E-07	0.00005	0.00000008	0.00004	0.00005	0.0000005	0.00006	0.006	0.000004
Adult Soil Intake/Long Exposure	0.0008	0.00000001	9.6E-09	0.00003	0.0000002	0.00001	0.00004	0.000001	0.00001	0.006	0.000002
Meteorological Location/Long Exposure	0.0005	0.000000006	5.4E-09	0.00001	0.0000001	0.000008	0.00002	0.0000006	0.000006	0.003	0.000001
Distance to Receptor/Long Exposure	0.0007	0.00000001	8.8E-09	0.00002	0.0000002	0.00001	0.00004	0.000001	0.000009	0.005	0.000002
Waste Concentration/ Adult Soil Intake	0.002	0.00000004	5.6E-08	0.0001	0.0000002	0.00009	0.0001	0.000001	0.0001	0.01	0.000008
Waste Concentration/ Meteorological Location	0.001	0.00000002	3.2E-08	0.00005	0.0000001	0.00005	0.00007	0.0000006	0.00007	0.008	0.000005
Waste Concentration/ Distance to Receptor	0.002	0.00000004	5.1E-08	0.00008	0.0000002	0.00008	0.0001	0.000001	0.0001	0.01	0.000007
Adult Soil Intake/ Meteorological Location	0.001	0.00000001	1.2E-09	0.00003	0.0000002	0.00002	0.00005	0.000001	0.00001	0.007	0.000002
Adult Soil Intake/ Distance to Receptor	0.002	0.00000002	2.0E-09	0.00004	0.0000004	0.00003	0.00008	0.000002	0.00002	0.01	0.000004
Meteorological Location/Distance to Receptor	0.0009	0.00000001	1.1E-09	0.00002	0.0000002	0.00001	0.00005	0.000001	0.00001	0.007	0.000002

Table H1-3d Home Gardener Individual Risk from All Ingestion Pathways for Utility Oil Co-Managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Arsenic	Barium	Boron	Cadmium	Chromium VI	Cobalt	Copper	Vanadium	Zinc
Central Tendency	0.0004	0.00000001	4.8E-10	0.00001	0.00000009	0.00001	0.00002	0.0000005	0.000007	0.003	0.000001
Single High-end Parameter											
Long Exposure	0.0004	0.00000001	4.7E-09	0.00001	0.00000009	0.00001	0.00002	0.0000005	0.000007	0.003	0.000001
Exposed Veg. Intake	0.0005	0.00000002	5.4E-10	0.00002	0.0000001	0.00002	0.00002	0.0000006	0.00001	0.003	0.000002
Root Veg.Intake	0.0004	0.00000001	4.8E-10	0.00001	0.00000009	0.00001	0.00002	0.0000005	0.000009	0.003	0.000001
Fruit Intake	0.0005	0.00000003	5.7E-10	0.00002	0.0000001	0.00002	0.00002	0.0000006	0.00002	0.003	0.000002
Constituent Conc.	0.001	0.00000004	2.7E-08	0.00006	0.00000009	0.00006	0.00005	0.0000005	0.0001	0.006	0.000006
Adult Soil Intake	0.0008	0.00000002	1.0E-09	0.00003	0.0000002	0.00002	0.00004	0.000001	0.00001	0.006	0.000002
Meteorological Location	0.0005	0.00000001	5.9E-10	0.00001	0.0000001	0.00001	0.00002	0.0000006	0.00001	0.003	0.000002
Distance To Receptor	0.0007	0.00000004	9.8E-10	0.00003	0.0000003	0.00002	0.00004	0.000001	0.00001	0.005	0.000003
Double High-end Parameters											
Exposed Veg. Intake/Long Exposure	0.0005	0.00000002	5.2E-09	0.00002	0.0000001	0.00002	0.00002	0.0000006	0.00001	0.003	0.000002
Root Veg. Intake/Long Exposure	0.0004	0.00000001	4.7E-09	0.00001	0.00000009	0.00001	0.00002	0.0000005	0.000009	0.003	0.000001
Fruit Intake/Long Exposure	0.0005	0.00000003	5.6E-09	0.00002	0.0000001	0.00002	0.00002	0.0000006	0.00002	0.003	0.000002
Constituent Conc./Long Exposure	0.001	0.00000004	2.7E-07	0.00006	0.00000009	0.00006	0.00005	0.0000005	0.0001	0.006	0.000006
Adult Soil Intake/Long Exposure	0.0008	0.00000002	9.9E-09	0.00003	0.0000002	0.00002	0.00004	0.000001	0.00001	0.006	0.000002
Meteorological Location/Long Exposure	0.0005	0.00000001	5.8E-09	0.00001	0.0000001	0.00001	0.00002	0.0000006	0.00001	0.003	0.000002
Distance to Receptor/Long Exposure	0.0007	0.00000004	9.6E-09	0.00003	0.0000003	0.00002	0.00004	0.000001	0.00001	0.005	0.000003
Exposed Veg. Intake/Root Veg. Intake	0.0005	0.00000002	5.4E-10	0.00002	0.0000001	0.00002	0.00002	0.0000006	0.00002	0.003	0.000002
Exposed Veg. Intake/ Fruit Intake	0.0005	0.00000004	6.3E-10	0.00003	0.0000001	0.00003	0.00002	0.0000006	0.00002	0.003	0.000003
Exposed Veg. Intake/Waste Concentration	0.001	0.00000007	3.1E-08	0.00009	0.0000001	0.0001	0.00005	0.0000006	0.0002	0.006	0.000009
Exposed Veg. Intake/Adult Soil Intake	0.0009	0.00000002	1.1E-09	0.00004	0.0000002	0.00002	0.00004	0.000001	0.00002	0.006	0.000003
Exposed Veg. Intake/Meteorological Location	0.0006	0.00000002	6.6E-10	0.00002	0.0000001	0.00002	0.00002	0.0000007	0.00002	0.003	0.000002
Exposed Veg. Intake/ Distance to Receptor	0.0008	0.00000007	1.1E-09	0.00003	0.0000004	0.00002	0.00005	0.000001	0.00002	0.006	0.000003
Root Veg. Intake/Fruit Intake	0.0005	0.00000003	5.8E-10	0.00002	0.0000001	0.00002	0.00002	0.0000006	0.00002	0.003	0.000002
Root Veg. Intake/Waste Concentration	0.001	0.00000004	2.8E-08	0.00007	0.00000009	0.00006	0.00005	0.0000005	0.0001	0.006	0.000006
Root Veg. Intake/Adult Soil Intake	0.0008	0.00000002	1.0E-09	0.00003	0.0000002	0.00002	0.00004	0.000001	0.00002	0.006	0.000002
Root Veg. Intake/ Meteorological Location	0.0005	0.00000001	6.0E-10	0.00001	0.0000001	0.00001	0.00002	0.0000006	0.00001	0.003	0.000002
Root Veg. Intake/ Distance to Receptor	0.0007	0.00000004	9.9E-10	0.00003	0.0000003	0.00002	0.00004	0.000001	0.00002	0.005	0.000003
Fruit Intake/Waste Concentration	0.001	0.0000001	3.3E-08	0.0001	0.0000001	0.0001	0.00006	0.0000006	0.0002	0.006	0.00001
Fruit Intake/Adult Soil Intake	0.0009	0.00000003	1.1E-09	0.00004	0.0000002	0.00002	0.00004	0.000001	0.00002	0.006	0.000003
Fruit Intake/ Meteorological Location	0.0006	0.00000003	7.0E-10	0.00002	0.0000001	0.00003	0.00002	0.0000007	0.00002	0.003	0.000002
Fruit Intake/ Distance to Receptor	0.0009	0.0000001	1.3E-09	0.00004	0.0000005	0.00003	0.00005	0.000001	0.00003	0.006	0.000004
Waste Concentration/ Adult Soil Intake	0.002	0.00000006	5.8E-08	0.0001	0.0000002	0.0001	0.0001	0.000001	0.0001	0.01	0.00001
Waste Concentration/ Meteorological Location	0.001	0.00000004	3.4E-08	0.00007	0.0000001	0.00008	0.00007	0.0000006	0.0001	0.008	0.000007
Waste Concentration/ Distance to Receptor	0.002	0.0000001	5.6E-08	0.0001	0.0000003	0.0001	0.0001	0.000001	0.0002	0.01	0.00001
Adult Soil Intake/ Meteorological Location	0.001	0.00000002	1.3E-09	0.00003	0.0000002	0.00003	0.00005	0.000001	0.00001	0.007	0.000003
Adult Soil Intake/ Distance to Receptor	0.002	0.00000005	2.1E-09	0.00005	0.0000005	0.00004	0.00008	0.000002	0.00003	0.01	0.000005
Meteorological Location/Distance to Receptor	0.001	0.00000004	1.2E-09	0.00003	0.0000003	0.00002	0.00005	0.000001	0.00002	0.007	0.000003

Table H1-3e Fisher Individual Risk from All Ingestion Pathways for Utility Oil Co-Managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Arsenic	Barium	Boron	Cadmium	Chromium VI	Cobalt	Copper	Vanadium	Zinc
Central Tendency	0.000008	0.000001	5.6E-11	0.00000003	0.0000007	0.0000001	0.000005	0.00000003	0.0000009	0.0001	0.0000001
Single High-end Parameter											
Long Exposure	0.000008	0.000001	5.5E-10	0.00000003	0.0000007	0.0000001	0.000005	0.00000003	0.0000009	0.0001	0.0000001
Fish Intake	0.000008	0.000001	6.2E-11	0.00000003	0.0000007	0.0000005	0.000005	0.00000003	0.0000009	0.0001	0.0000004
Waste Concentration	0.00002	0.000004	3.2E-09	0.0000001	0.0000007	0.0000007	0.00002	0.00000003	0.00001	0.0003	0.0000005
Meteorological Location	0.000001	0.00000005	5.3E-12	0.00000001	0.00000004	0.00000002	0.0000004	0.000000004	0.00000008	0.00002	0.00000001
Distance to Receptor	0.00001	0.000001	6.6E-11	0.00000005	0.0000007	0.0000002	0.000006	0.00000004	0.000001	0.0002	0.0000001
Double High-end Parameters											
Fish Intake/Long Exposure	0.000008	0.000001	6.1E-10	0.00000003	0.0000007	0.0000005	0.000005	0.00000003	0.0000009	0.0001	0.0000004
Waste Concentration/Long Exposure	0.00002	0.000004	3.1E-08	0.0000001	0.0000007	0.0000007	0.00002	0.00000003	0.00001	0.0003	0.0000005
Meteorological Location/Long Exposure	0.000001	0.00000005	5.2E-11	0.00000001	0.00000004	0.00000002	0.0000004	0.000000004	0.00000008	0.00002	0.00000001
Distance to Receptor/Long Exposure	0.00001	0.000001	6.5E-10	0.00000005	0.0000007	0.0000002	0.000006	0.00000004	0.000001	0.0002	0.0000001
Fish Intake/Waste Concentration	0.00002	0.000004	3.5E-09	0.0000001	0.0000007	0.000002	0.00002	0.00000003	0.00001	0.0003	0.000002
Fish Intake/Meteorological Location	0.000001	0.00000005	5.9E-12	0.00000001	0.00000004	0.0000001	0.0000004	0.000000004	0.00000008	0.00002	0.00000005
Fish Intake/Distance to Receptor	0.00001	0.000001	7.3E-11	0.00000005	0.0000007	0.0000007	0.000006	0.00000004	0.000001	0.0002	0.0000005
Waste Concentration/Meteorological Location	0.000004	0.0000002	3.0E-10	0.00000005	0.00000004	0.0000002	0.000001	0.000000004	0.000001	0.00004	0.00000006
Waste Concentration/Distance to Receptor	0.00003	0.000004	3.8E-09	0.0000002	0.0000007	0.000001	0.00002	0.00000004	0.00001	0.0004	0.0000006
Meteorological Location/Distance to Receptor	0.000004	0.00000006	1.3E-11	0.00000003	0.00000005	0.00000008	0.0000009	0.000000009	0.0000002	0.00004	0.00000004

Table H1-4a Farmer Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.000002	0.000001	0.0001	2.7E-09	0.00004	4.5E-10	0.00000003	0.00002	0.000002	0.0000002	0.0000003
Single High-end Parameter											
Long Exposure	0.000002	0.000001	0.0001	8.0E-09	0.00004	1.3E-09	0.00000003	0.00002	0.000002	0.0000002	0.0000003
Beef intake	0.000005	0.000001	0.001	3.2E-09	0.00004	9.0E-10	0.00000003	0.00002	0.000005	0.000001	0.0000004
Dairy Intake	0.000004	0.000005	0.0003	8.6E-09	0.00005	4.5E-10	0.00000003	0.00002	0.000005	0.0000005	0.000001
Exposed Veg. Intake	0.000002	0.000001	0.0001	2.9E-09	0.00007	7.2E-10	0.00000004	0.00004	0.000002	0.0000003	0.0000004
Root Veg. Intake	0.000002	0.000001	0.0001	2.9E-09	0.00006	5.7E-10	0.00000003	0.00004	0.000002	0.0000002	0.0000004
Fruit Intake	0.000003	0.000001	0.0002	3.4E-09	0.0001	1.2E-09	0.0000001	0.00007	0.000002	0.0000003	0.0000004
Waste Concentration	0.000005	0.000003	0.0003	2.4E-08	0.0004	8.3E-10	0.00000008	0.00008	0.000009	0.0000002	0.00002
Adult Soil Intake	0.000002	0.000001	0.0001	2.7E-09	0.00004	5.8E-10	0.00000003	0.00002	0.000002	0.0000002	0.0000003
Meteorological Location	0.000002	0.000001	0.0001	2.8E-09	0.00005	5.3E-10	0.00000003	0.00003	0.000002	0.0000002	0.0000003
Distance to Receptor	0.000004	0.00001	0.0007	1.2E-08	0.00006	1.3E-09	0.0000002	0.00003	0.00001	0.0000009	0.000003
WMU Area	0.000007	0.000005	0.0006	1.1E-08	0.0002	1.9E-09	0.0000001	0.00008	0.000007	0.0000009	0.000001
Double High-end Parameters											
Beef Intake/ Long Exposure	0.000005	0.000001	0.001	9.7E-09	0.00004	2.7E-09	0.00000003	0.00002	0.000005	0.000001	0.0000004
Dairy Intake/Long Exposure	0.000004	0.000005	0.0003	2.6E-08	0.00005	1.3E-09	0.00000003	0.00002	0.000005	0.0000005	0.000001
Exposed Veg. Intake/ Long Exposure	0.000002	0.000001	0.0001	8.8E-09	0.00007	2.2E-09	0.00000004	0.00004	0.000002	0.0000003	0.0000004
Root Veg. Intake/Long Exposure	0.000002	0.000001	0.0001	8.6E-09	0.00006	1.7E-09	0.00000003	0.00004	0.000002	0.0000002	0.0000004
Fruit Intake/ Long Exposure	0.000003	0.000001	0.0002	1.0E-08	0.0001	3.6E-09	0.0000001	0.00007	0.000002	0.0000003	0.0000004
Waste Concentration/Long Exposure	0.000005	0.000003	0.0003	7.1E-08	0.0004	2.5E-09	0.00000008	0.00008	0.000009	0.0000002	0.00002
Adult Soil Intake/Long Exposure	0.000002	0.000001	0.0001	8.1E-09	0.00004	1.7E-09	0.00000003	0.00002	0.000002	0.0000002	0.0000003
Meteorlogical Location/Long Exposure	0.000002	0.000001	0.0001	8.5E-09	0.00005	1.6E-09	0.00000003	0.00003	0.000002	0.0000002	0.0000003
Distance to Receptor/Long Exposure	0.000004	0.00001	0.0007	3.6E-08	0.00006	4.0E-09	0.0000002	0.00003	0.00001	0.0000009	0.000003
WMU Area/Long Exposure	0.000007	0.000005	0.0006	3.3E-08	0.0002	5.7E-09	0.0000001	0.00008	0.000007	0.0000009	0.000001
Beef Intake/ Dairy Intake	0.000008	0.000005	0.001	9.2E-09	0.00006	9.0E-10	0.00000003	0.00002	0.000008	0.000001	0.000001
Beef Intake/ Exposed Veg. Intake											
Beef Intake/Root Vegetable Intake	0.000006	0.000001	0.001	3.5E-09	0.00006	1.0E-09	0.00000003	0.00004	0.000006	0.000001	0.0000004
Beef Intake/Fruit Intake	0.000007	0.000001	0.001	4.0E-09	0.0001	1.7E-09	0.0000001	0.00007	0.000006	0.000001	0.0000005
Beef Intake/ Waste Concentration	0.00001	0.000004	0.002	2.9E-08	0.0004	1.7E-09	0.00000008	0.00008	0.00003	0.000001	0.00002
Beef Intake/Adult Soil Intake	0.000006	0.000001	0.001	3.3E-09	0.00004	1.0E-09	0.00000003	0.00002	0.000006	0.000001	0.0000004
Beef Intake/Meteorological Location	0.000007	0.000001	0.001	3.5E-09	0.00005	1.0E-09	0.00000003	0.00003	0.000004	0.000001	0.0000004
Beef Intake/Distance to Receptor	0.00001	0.00001	0.005	1.5E-08	0.00006	3.3E-09	0.0000002	0.00003	0.00003	0.000006	0.000004
Beef Intake/WMU Area	0.00003	0.000006	0.004	1.3E-08	0.0002	3.8E-09	0.0000001	0.00008	0.00002	0.000005	0.000001
Dairy Intake/Exposed Vegetable Intake	0.000004	0.000005	0.0003	8.9E-09	0.00008	7.3E-10	0.00000004	0.00004	0.000005	0.0000006	0.000001
Dairy Intake/Root Vegetable Intake	0.000004	0.000005	0.0003	8.8E-09	0.00007	5.7E-10	0.00000003	0.00004	0.000005	0.0000005	0.000001
Dairy Intake/Fruit Intake	0.000006	0.000005	0.0003	9.3E-09	0.0001	1.2E-09	0.0000001	0.00007	0.000005	0.0000006	0.000001
Dairy Intake/Waste Concentration	0.00001	0.00001	0.0006	7.7E-08	0.0005	8.3E-10	0.00000008	0.00008	0.00002	0.0000006	0.00006
Dairy Intake/Adult Soil Intake	0.000004	0.000005	0.0003	8.6E-09	0.00006	5.8E-10	0.00000003	0.00002	0.000005	0.0000005	0.000001
Dairy Intake/ Meteorological Location	0.000005	0.000004	0.0003	9.1E-09	0.00007	5.3E-10	0.00000003	0.00003	0.000005	0.0000005	0.0000009
Dairy Intake/Distance to Receptor	0.00001	0.00004	0.001	4.0E-08	0.00008	1.3E-09	0.0000002	0.00003	0.00003	0.000002	0.000009

Table H1-4a Farmer Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Dairy Intake/ WMU Area	0.00001	0.00002	0.001	3.5E-08	0.0002	1.9E-09	0.0000001	0.00008	0.00002	0.000002	0.000005
Exposed Veg. Intake/ Root Veg. Intake	0.000003	0.000001	0.0001	3.2E-09	0.00009	8.5E-10	0.00000004	0.00006	0.000002	0.0000003	0.0000004
Exposed Veg. Intake/ Fruit Intake	0.000004	0.000001	0.0002	3.7E-09	0.0001	1.5E-09	0.0000001	0.00009	0.000003	0.0000003	0.0000005
Exposed Veg. Intake/Waste Concentration	0.000006	0.000003	0.0004	2.6E-08	0.0008	1.4E-09	0.0000001	0.0002	0.00001	0.0000003	0.00002
Exposed Veg. Intake/Adult Soil Intake	0.000002	0.000001	0.0001	3.0E-09	0.00007	8.5E-10	0.00000004	0.00004	0.000002	0.0000003	0.0000004
Exposed Veg. Intake/Meteorological Location	0.000003	0.000001	0.0002	3.2E-09	0.00009	8.7E-10	0.00000004	0.00005	0.000002	0.0000003	0.0000004
Exposed Veg. Intake/Distance to Receptor	0.000005	0.00001	0.0007	1.3E-08	0.0001	2.1E-09	0.0000004	0.00007	0.00001	0.000001	0.000004
Exposed Veg. Intake/WMU Area	0.00001	0.000005	0.0006	1.2E-08	0.0003	3.1E-09	0.0000002	0.0002	0.000008	0.000001	0.000001
Root Veg. Intake/Fruit Intake	0.000004	0.000001	0.0002	3.6E-09	0.0001	1.3E-09	0.0000001	0.00009	0.000003	0.0000003	0.0000005
Root Veg. Intake/Waste Concentration	0.000005	0.000003	0.0003	2.5E-08	0.0006	1.1E-09	0.00000008	0.0001	0.00001	0.0000002	0.00002
Root Veg. Intake/Adult Soil Intake	0.000002	0.000001	0.0001	2.9E-09	0.00006	7.0E-10	0.00000003	0.00004	0.000002	0.0000002	0.0000004
Root Veg. Intake/Meteorological Location	0.000003	0.000001	0.0002	3.1E-09	0.00007	6.9E-10	0.00000003	0.00005	0.000002	0.0000002	0.0000004
Root Veg. Intake/Distance to Receptor	0.000005	0.00001	0.0007	1.2E-08	0.00007	1.5E-09	0.0000002	0.00005	0.00001	0.0000009	0.000003
Root Veg. Intake/WMU Area	0.00001	0.000005	0.0006	1.2E-08	0.0002	2.5E-09	0.0000001	0.0001	0.000008	0.0000009	0.000001
Fruit Intake/Waste Concentration	0.000008	0.000003	0.0004	3.0E-08	0.001	2.2E-09	0.0000003	0.0002	0.00001	0.0000004	0.00003
Fruit Intake/Adult Soil Intake	0.000004	0.000001	0.0002	3.4E-09	0.0001	1.3E-09	0.0000001	0.00007	0.000003	0.0000003	0.0000004
Fruit Intake/Meteorological Location	0.000004	0.000001	0.0002	3.7E-09	0.0001	1.4E-09	0.00000009	0.00008	0.000002	0.0000004	0.0000004
Fruit Intake/Distance to Receptor	0.000007	0.00001	0.0008	1.4E-08	0.0001	4.2E-09	0.0000009	0.0001	0.00002	0.000001	0.000004
Fruit Intake/WMU Area	0.00001	0.000006	0.0006	1.4E-08	0.0005	5.1E-09	0.0000004	0.0003	0.00001	0.000001	0.000002
Waste Concentration/Adult Soil Intake	0.000005	0.000003	0.0004	2.4E-08	0.0004	1.1E-09	0.00000008	0.00008	0.000009	0.0000002	0.00002
Waste Concentration/Meteorological Location	0.000006	0.000003	0.0003	2.5E-08	0.0005	9.9E-10	0.00000007	0.0001	0.000008	0.0000003	0.00001
Waste Concentration/Distance to Receptor	0.00001	0.00002	0.001	1.1E-07	0.0006	2.5E-09	0.0000006	0.0001	0.00006	0.000001	0.0001
Waste Concentration/WMU Area	0.00002	0.00001	0.001	9.8E-08	0.002	3.6E-09	0.0000003	0.0004	0.00003	0.000001	0.00007
Adult Soil Intake/Meteorological Location	0.000002	0.000001	0.0002	2.9E-09	0.00005	7.0E-10	0.00000003	0.00003	0.000002	0.0000002	0.0000004
Adult Soil Intake/Distance to Receptor	0.000004	0.00001	0.0007	1.2E-08	0.00006	1.5E-09	0.0000002	0.00003	0.00001	0.000001	0.000003
Adult Soil Intake/WMU Area	0.000008	0.000005	0.0006	1.1E-08	0.0002	2.5E-09	0.0000001	0.00008	0.000007	0.0000009	0.000001
Meteorological Location/Distance to Receptor	0.000006	0.000008	0.0006	1.1E-08	0.00009	1.5E-09	0.0000001	0.00005	0.000009	0.000001	0.000002
Meteorological Location/WMU Area	0.00001	0.000005	0.0006	1.2E-08	0.0002	2.3E-09	0.00000008	0.0001	0.000007	0.000001	0.000001
Distance to Receptor/WMU Area	0.000009	0.00003	0.001	2.7E-08	0.00009	2.7E-09	0.0000006	0.00005	0.00003	0.000002	0.000007

Table H1-4b Child of Farmer Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.0001	0.0000024	0.0094	3.0E-08	0.001	8.8E-08	0.000002	0.00031	0.0001	0.00001	0.0000034
Single High-end Parameter											
Long Exposure	0.0001	0.0000024	0.0094	3.7E-08	0.001	1.0E-07	0.000002	0.00031	0.0001	0.00001	0.0000034
Beef intake	0.0001	0.0000024	0.0097	3.0E-08	0.001	8.8E-08	0.000002	0.00031	0.0001	0.000011	0.0000034
Dairy Intake	0.0001	0.0000044	0.0094	3.3E-08	0.001	8.8E-08	0.000002	0.00031	0.0001	0.000011	0.0000039
Exposed Veg. Intake	0.0001	0.0000024	0.0094	3.0E-08	0.001	8.8E-08	0.000002	0.00033	0.0001	0.00001	0.0000034
Root Veg. Intake	0.0001	0.0000024	0.0094	3.0E-08	0.001	8.8E-08	0.000002	0.00031	0.0001	0.00001	0.0000034
Fruit Intake	0.0001	0.0000024	0.0094	3.0E-08	0.0011	8.8E-08	0.0000021	0.00035	0.0001	0.00001	0.0000035
Waste Concentration	0.00031	0.0000048	0.021	2.7E-07	0.01	1.6E-07	0.000007	0.001	0.00051	0.00001	0.00012
Adult Soil Intake	0.0001	0.0000024	0.0094	3.1E-08	0.001	9.0E-08	0.000002	0.00031	0.0001	0.00001	0.0000034
Child Soil Intake	0.0003	0.000003	0.02	7.4E-08	0.004	2.3E-07	0.000006	0.00091	0.0003	0.00003	0.0000074
Meteorological Location	0.0001	0.0000015	0.01	3.7E-08	0.002	1.1E-07	0.000003	0.00041	0.0001	0.00001	0.0000033
Distance to Receptor	0.00021	0.000011	0.021	6.6E-08	0.002	1.7E-07	0.0000051	0.00061	0.00022	0.000022	0.0000092
WMU Area	0.00041	0.0000073	0.041	1.3E-07	0.0061	3.9E-07	0.00001	0.002	0.00041	0.000052	0.000011
Double High-end Parameters											
Beef Intake/ Long Exposure	0.0001	0.0000024	0.0097	3.8E-08	0.001	1.0E-07	0.000002	0.00031	0.0001	0.000011	0.0000034
Dairy Intake/Long Exposure	0.0001	0.0000044	0.0094	4.4E-08	0.001	1.0E-07	0.000002	0.00031	0.0001	0.000011	0.0000039
Exposed Veg. Intake/ Long Exposure	0.0001	0.0000024	0.0094	3.8E-08	0.001	1.0E-07	0.000002	0.00033	0.0001	0.00001	0.0000034
Root Veg. Intake/Long Exposure	0.0001	0.0000024	0.0094	3.7E-08	0.001	1.0E-07	0.000002	0.00031	0.0001	0.00001	0.0000034
Fruit Intake/ Long Exposure	0.0001	0.0000024	0.0094	3.9E-08	0.0011	1.0E-07	0.0000021	0.00035	0.0001	0.00001	0.0000035
Waste Concentration/Long Exposure	0.00031	0.0000048	0.021	3.3E-07	0.01	1.9E-07	0.000007	0.001	0.00051	0.00001	0.00012
Adult Soil Intake/Long Exposure	0.0001	0.0000024	0.0094	4.3E-08	0.001	1.2E-07	0.000002	0.00031	0.0001	0.00001	0.0000034
Child Soil Intake/Long Exposure	0.0003	0.000003	0.02	8.1E-08	0.004	2.4E-07	0.000006	0.00091	0.0003	0.00003	0.0000074
Meteorological Location/Long Exposure	0.0001	0.0000015	0.01	4.5E-08	0.002	1.2E-07	0.000003	0.00041	0.0001	0.00001	0.0000033
Distance to Receptor/Long Exposure	0.00021	0.000011	0.021	8.9E-08	0.002	2.0E-07	0.0000051	0.00061	0.00022	0.000022	0.0000092
WMU Area/Long Exposure											
Beef Intake/ Dairy Intake	0.0001	0.0000044	0.0097	3.3E-08	0.001	8.8E-08	0.000002	0.00031	0.00011	0.000011	0.0000039
Beef Intake/ Exposed Veg. Intake	0.0001	0.0000024	0.0097	3.0E-08	0.001	8.8E-08	0.000002	0.00033	0.0001	0.000011	0.0000035
Beef Intake/Root Vegetable Intake	0.0001	0.0000024	0.0097	3.0E-08	0.001	8.8E-08	0.000002	0.00031	0.0001	0.000011	0.0000034
Beef Intake/Fruit Intake	0.0001	0.0000025	0.0097	3.1E-08	0.0011	8.8E-08	0.0000021	0.00035	0.0001	0.000011	0.0000035
Beef Intake/Waste Concentration	0.00031	0.000005	0.021	2.7E-07	0.01	1.6E-07	0.000007	0.001	0.00052	0.000011	0.00012
Beef Intake/Adult Soil Intake	0.0001	0.0000024	0.0097	3.1E-08	0.001	9.0E-08	0.000002	0.00031	0.0001	0.000011	0.0000034
Beef Intake/Child Soil Intake	0.0003	0.000003	0.021	7.4E-08	0.004	2.3E-07	0.000006	0.00091	0.0003	0.000031	0.0000074
Beef Intake/Meteorological Location	0.0001	0.0000015	0.011	3.7E-08	0.002	1.1E-07	0.000003	0.00041	0.0001	0.000011	0.0000033
Beef Intake/Distance to Receptor	0.00021	0.000012	0.023	6.7E-08	0.002	1.7E-07	0.0000051	0.00061	0.00022	0.000024	0.0000093
Beef Intake/WMU Area	0.00042	0.0000075	0.043	1.3E-07	0.0061	3.9E-07	0.00001	0.002	0.00041	0.000053	0.000011
Dairy Intake/Exposed Vegetable Intake	0.0001	0.0000044	0.0094	3.3E-08	0.0011	8.8E-08	0.000002	0.00033	0.0001	0.000011	0.0000039
Dairy Intake/Root Vegetable Intake	0.0001	0.0000044	0.0094	3.3E-08	0.001	8.8E-08	0.000002	0.00031	0.0001	0.000011	0.0000039
Dairy Intake/Fruit Intake	0.0001	0.0000044	0.0094	3.3E-08	0.0011	8.8E-08	0.0000021	0.00035	0.0001	0.000011	0.000004
Dairy Intake/Waste Concentration	0.00031	0.0000098	0.021	2.9E-07	0.01	1.6E-07	0.000007	0.001	0.00052	0.000011	0.00014

Table H1-4b Child of Farmer Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Dairy Intake/ Adult Soil Intake	0.0001	0.0000044	0.0094	3.3E-08	0.001	9.0E-08	0.000002	0.00031	0.0001	0.000011	0.0000039
Dairy Intake/ Child Soil Intake	0.0003	0.000005	0.02	7.6E-08	0.004	2.3E-07	0.000006	0.00091	0.0003	0.000031	0.0000079
Dairy Intake/ Meteorological Location	0.0001	0.0000035	0.01	3.9E-08	0.002	1.1E-07	0.000003	0.00041	0.0001	0.000011	0.0000037
Dairy Intake/Distance to Receptor	0.00021	0.000031	0.022	7.8E-08	0.002	1.7E-07	0.0000051	0.00061	0.00023	0.000022	0.000013
Dairy Intake/WMU Area	0.00042	0.000011	0.042	1.4E-07	0.0061	3.9E-07	0.00001	0.002	0.00041	0.000052	0.000013
Exposed Veg. Intake/ Root Veg. Intake	0.0001	0.0000024	0.0094	3.0E-08	0.001	8.8E-08	0.000002	0.00033	0.0001	0.00001	0.0000034
Exposed Veg. Intake/ Fruit Intake	0.0001	0.0000025	0.0094	3.1E-08	0.0011	8.9E-08	0.0000021	0.00037	0.0001	0.00001	0.0000035
Exposed Veg. Intake/Waste Concentration	0.00031	0.0000049	0.021	2.7E-07	0.01	1.6E-07	0.0000071	0.0011	0.00051	0.00001	0.00012
Exposed Veg. Intake/Adult Soil Intake	0.0001	0.0000024	0.0094	3.1E-08	0.001	9.0E-08	0.000002	0.00033	0.0001	0.00001	0.0000034
Exposed Veg. Intake/Child Soil Intake	0.0003	0.000003	0.02	7.4E-08	0.004	2.3E-07	0.000006	0.00093	0.0003	0.00003	0.0000074
Exposed Veg. Intake/Meteorological Location	0.0001	0.0000015	0.01	3.7E-08	0.002	1.1E-07	0.000003	0.00043	0.0001	0.00001	0.0000033
Exposed Veg. Intake/Distance to Receptor	0.00021	0.000011	0.021	6.6E-08	0.0021	1.7E-07	0.0000052	0.00063	0.00022	0.000022	0.0000093
Exposed Veg. Intake/WMU Area	0.00041	0.0000074	0.041	1.3E-07	0.0062	3.9E-07	0.00001	0.0021	0.00041	0.000052	0.000011
Root Veg. Intake/Fruit Intake	0.0001	0.0000024	0.0094	3.0E-08	0.0011	8.8E-08	0.0000021	0.00036	0.0001	0.00001	0.0000035
Root Veg. Intake/Waste Concentration	0.00031	0.0000048	0.021	2.7E-07	0.01	1.6E-07	0.000007	0.001	0.00051	0.00001	0.00012
Root Veg. Intake/Adult Soil Intake	0.0001	0.0000024	0.0094	3.1E-08	0.001	9.0E-08	0.000002	0.00031	0.0001	0.00001	0.0000034
Root Veg. Intake/Child Soil Intake	0.0003	0.000003	0.02	7.4E-08	0.004	2.3E-07	0.000006	0.00091	0.0003	0.00003	0.0000074
Root Veg. Intake/Meteorological Location	0.0001	0.0000015	0.01	3.7E-08	0.002	1.1E-07	0.000003	0.00041	0.0001	0.00001	0.0000033
Root Veg. Intake/Distance to Receptor	0.00021	0.000011	0.021	6.6E-08	0.002	1.7E-07	0.0000051	0.00062	0.00022	0.000022	0.0000092
Root Veg. Intake/WMU Area	0.00041	0.0000073	0.041	1.3E-07	0.0061	3.9E-07	0.00001	0.002	0.00041	0.000052	0.000011
Fruit Intake/Waste Concentration	0.00031	0.0000051	0.021	2.7E-07	0.011	1.6E-07	0.0000073	0.0012	0.00052	0.000011	0.00013
Fruit Intake/Adult Soil Intake	0.0001	0.0000024	0.0094	3.1E-08	0.0011	9.0E-08	0.0000021	0.00035	0.0001	0.00001	0.0000035
Fruit Intake/Child Soil Intake	0.0003	0.000003	0.02	7.4E-08	0.0041	2.3E-07	0.0000061	0.00095	0.0003	0.00003	0.0000075
Fruit Intake/Meteorological Location	0.0001	0.0000015	0.01	3.7E-08	0.0021	1.1E-07	0.0000031	0.00047	0.0001	0.00001	0.0000034
Fruit Intake/Distance to Receptor	0.00021	0.000012	0.022	6.8E-08	0.0021	1.7E-07	0.0000058	0.00068	0.00022	0.000022	0.0000098
Fruit Intake/WMU Area	0.00041	0.0000077	0.041	1.3E-07	0.0065	3.9E-07	0.00001	0.0022	0.00041	0.000052	0.000011
Waste Concentration/ Adult Soil Intake	0.00031	0.0000048	0.021	2.7E-07	0.01	1.7E-07	0.000007	0.001	0.00051	0.00001	0.00012
Waste Concentration/ Child Soil Intake	0.00071	0.0000061	0.051	6.6E-07	0.04	4.2E-07	0.00002	0.004	0.001	0.00003	0.00032
Waste Concentration/Meteorological Location	0.00031	0.000004	0.021	3.3E-07	0.02	2.0E-07	0.000008	0.002	0.00061	0.00002	0.00021
Waste Concentration/Distance to Receptor	0.00052	0.000033	0.043	5.9E-07	0.03	3.2E-07	0.00001	0.0031	0.0011	0.000032	0.00041
Waste Concentration/WMU Area	0.001	0.000013	0.083	***1.2E-06***	0.071	7.2E-07	0.00003	0.0062	0.002	0.000062	0.00067
Adult Soil Intake/Child Soil Intake	0.0003	0.000003	0.02	7.4E-08	0.004	2.3E-07	0.000006	0.00091	0.0003	0.00003	0.0000074
Adult Soil Intake/Meteorological Location	0.0001	0.0000015	0.01	3.7E-08	0.002	1.1E-07	0.000003	0.00041	0.0001	0.00001	0.0000033
Adult Soil Intake/Distance to Receptor	0.00021	0.000011	0.021	6.7E-08	0.002	1.8E-07	0.0000051	0.00061	0.00022	0.000022	0.0000092
Adult Soil Intake/WMU Area	0.00041	0.0000073	0.041	1.3E-07	0.0061	3.9E-07	0.00001	0.002	0.00041	0.000052	0.000011
Child Soil Intake/ Meteorological Location	0.0003	0.0000021	0.03	9.1E-08	0.004	2.8E-07	0.000007	0.001	0.0003	0.00003	0.0000093
Child Soil Intake/Distance to Receptor	0.00051	0.000012	0.041	1.5E-07	0.006	4.4E-07	0.00001	0.002	0.00052	0.000062	0.000013
Child Soil Intake/WMU Area	0.001	0.00001	0.1	3.2E-07	0.02	9.9E-07	0.00003	0.004	0.001	0.0001	0.000031
Meteorological Location/Distance to Receptor	0.00021	0.00001	0.021	7.9E-08	0.0031	2.1E-07	0.0000061	0.00073	0.00021	0.000032	0.0000092
Meteorological Location/WMU Area	0.00051	0.0000072	0.051	1.6E-07	0.0071	4.7E-07	0.00001	0.0021	0.00051	0.000062	0.000021
Distance to Receptor/WMU Area	0.00021	0.000032	0.024	7.9E-08	0.0021	1.7E-07	0.0000053	0.00062	0.00023	0.000023	0.000013

Table H1-4c Adult Resident Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.000002	0.000000008	0.0002	3.5E-10	0.00003	1.1E-09	0.00000005	0.000008	0.000002	0.0000003	0.00000006
Single High-end Parameter											
Long Exposure	0.000002	0.000000008	0.0002	3.2E-09	0.00003	1.0E-08	0.00000005	0.000008	0.000002	0.0000003	0.00000006
Constituent Conc.	0.000006	0.00000002	0.0004	3.1E-09	0.0003	2.1E-09	0.0000002	0.00003	0.00001	0.0000003	0.000003
Adult Soil Intake	0.000005	0.00000002	0.0004	7.7E-10	0.00007	2.4E-09	0.0000001	0.00002	0.000005	0.0000006	0.0000001
Meteorological Location	0.000003	0.00000001	0.0002	4.3E-10	0.00004	1.3E-09	0.00000007	0.00001	0.000003	0.0000003	0.00000008
Distance To Receptor	0.000005	0.00000002	0.0004	7.1E-10	0.00005	2.2E-09	0.0000001	0.00001	0.000005	0.0000005	0.0000001
WMU Area	0.00001	0.00000003	0.0009	1.5E-09	0.0001	4.9E-09	0.0000002	0.00004	0.00001	0.000001	0.0000003
Double High-end Parameters											
Constituent Conc./Long Exposure	0.000006	0.00000002	0.0004	2.8E-08	0.0003	1.9E-08	0.0000002	0.00003	0.00001	0.0000003	0.000003
Adult Soil Intake/Long Exposure	0.000005	0.00000002	0.0004	7.0E-09	0.00007	2.2E-08	0.0000001	0.00002	0.000005	0.0000006	0.0000001
Meteorological Location/Long Exposure	0.000003	0.00000001	0.0002	4.0E-09	0.00004	1.2E-08	0.00000007	0.00001	0.000003	0.0000003	0.00000008
Distance to Receptor/Long Exposure	0.000005	0.00000002	0.0004	6.4E-09	0.00005	2.0E-08	0.0000001	0.00001	0.000005	0.0000005	0.0000001
WMU Area/Long Exposure	0.00001	0.00000003	0.0009	1.4E-08	0.0001	4.4E-08	0.0000002	0.00004	0.00001	0.000001	0.0000003
Waste Concentration/ Adult Soil Intake	0.00001	0.00000004	0.0009	6.9E-09	0.0008	4.5E-09	0.0000003	0.00007	0.00002	0.0000007	0.000007
Waste Concentration/ Meteorological Location	0.000007	0.00000002	0.0005	3.9E-09	0.0004	2.5E-09	0.0000002	0.00004	0.00001	0.0000004	0.000004
Waste Concentration/ Distance to Receptor	0.00001	0.00000004	0.0008	6.3E-09	0.0006	4.0E-09	0.0000003	0.00006	0.00002	0.0000006	0.000006
Waste Concentration/ WMU Area	0.00003	0.00000008	0.002	1.4E-08	0.002	9.0E-09	0.0000007	0.0001	0.00005	0.000001	0.00001
Adult Soil Intake/ Meteorological Location	0.000006	0.00000002	0.0005	9.6E-10	0.00008	3.0E-09	0.0000001	0.00002	0.000006	0.0000007	0.0000002
Adult Soil Intake/ Distance to Receptor	0.00001	0.00000004	0.0009	1.6E-09	0.0001	4.7E-09	0.0000002	0.00003	0.00001	0.000001	0.0000003
Adult Soil Intake/ WMU Area	0.00002	0.00000008	0.002	3.4E-09	0.0003	1.1E-08	0.0000005	0.00008	0.00002	0.000002	0.0000006
Meteorological Location/Distance to Receptor	0.000005	0.00000002	0.0005	8.8E-10	0.00006	2.6E-09	0.0000001	0.00002	0.000006	0.0000006	0.0000002
Meteorological Location/WMU Area	0.00001	0.00000004	0.001	1.9E-09	0.0002	5.9E-09	0.0000003	0.00004	0.00001	0.000001	0.0000004
Distance to Receptor/WMU Area	0.000005	0.00000002	0.0004	7.2E-10	0.00005	2.2E-09	0.0000001	0.00002	0.000005	0.0000005	0.0000001

Table H1-4d Home Gardener Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.000002	0.00000002	0.0002	3.8E-10	0.00004	1.1E-09	0.00000006	0.00001	0.000002	0.0000003	0.00000007
Single High-end Parameter											
Long Exposure	0.000002	0.00000002	0.0002	3.4E-09	0.00004	1.0E-08	0.00000006	0.00001	0.000002	0.0000003	0.00000007
Exposed Veg. Intake	0.000002	0.00000004	0.0002	4.2E-10	0.00006	1.2E-09	0.00000007	0.00002	0.000002	0.0000003	0.00000008
Root Veg.Intake	0.000002	0.00000002	0.0002	3.8E-10	0.00004	1.1E-09	0.00000006	0.00001	0.000002	0.0000003	0.00000007
Fruit Intake	0.000003	0.00000005	0.0002	4.5E-10	0.00006	1.2E-09	0.00000008	0.00003	0.000002	0.0000003	0.00000009
Constituent Conc.	0.000006	0.00000005	0.0004	3.4E-09	0.0004	2.1E-09	0.0000002	0.00005	0.00001	0.0000003	0.000003
Adult Soil Intake	0.000005	0.00000003	0.0004	8.0E-10	0.00008	2.5E-09	0.0000001	0.00003	0.000005	0.0000006	0.0000001
Meteorological Location	0.000003	0.00000002	0.0002	4.7E-10	0.00005	1.4E-09	0.00000008	0.00002	0.000003	0.0000003	0.00000009
Distance To Receptor	0.000005	0.00000007	0.0004	7.8E-10	0.00006	2.2E-09	0.0000002	0.00002	0.000005	0.0000005	0.0000002
WMU Area	0.00001	0.00000007	0.0009	1.6E-09	0.0001	5.0E-09	0.0000002	0.00006	0.00001	0.000001	0.0000003
Double High-end Parameters											
Exposed Veg. Intake/Long Exposure	0.000002	0.00000004	0.0002	3.8E-09	0.00006	1.1E-08	0.00000007	0.00002	0.000002	0.0000003	0.00000008
Root Veg. Intake/Long Exposure	0.000002	0.00000002	0.0002	3.5E-09	0.00004	1.0E-08	0.00000006	0.00001	0.000002	0.0000003	0.00000007
Fruit Intake/Long Exposure	0.000003	0.00000005	0.0002	4.1E-09	0.00006	1.1E-08	0.00000008	0.00003	0.000002	0.0000003	0.00000009
Constituent Conc./Long Exposure	0.000006	0.00000005	0.0004	3.0E-08	0.0004	1.9E-08	0.0000002	0.00005	0.00001	0.0000003	0.000003
Adult Soil Intake/Long Exposure	0.000005	0.00000003	0.0004	7.2E-09	0.00008	2.2E-08	0.0000001	0.00003	0.000005	0.0000006	0.0000001
Meteorological Location/Long Exposure	0.000003	0.00000002	0.0002	4.2E-09	0.00005	1.3E-08	0.00000008	0.00002	0.000003	0.0000003	0.00000009
Distance to Receptor/Long Exposure	0.000005	0.00000007	0.0004	7.1E-09	0.00006	2.0E-08	0.0000002	0.00002	0.000005	0.0000005	0.0000002
WMU Area/Long Exposure	0.00001	0.00000007	0.0009	1.5E-08	0.0001	4.5E-08	0.0000002	0.00006	0.00001	0.000001	0.0000003
Exposed Veg. Intake/Root Veg. Intake	0.000002	0.00000004	0.0002	4.3E-10	0.00006	1.2E-09	0.00000007	0.00002	0.000002	0.0000003	0.00000008
Exposed Veg. Intake/ Fruit Intake	0.000003	0.00000007	0.0002	4.9E-10	0.00008	1.2E-09	0.00000009	0.00004	0.000002	0.0000004	0.0000001
Exposed Veg. Intake/Waste Concentration	0.000007	0.00000008	0.0004	3.8E-09	0.0006	2.2E-09	0.0000003	0.00009	0.00001	0.0000003	0.000004
Exposed Veg. Intake/Adult Soil Intake	0.000005	0.00000005	0.0004	8.4E-10	0.0001	2.5E-09	0.0000001	0.00003	0.000005	0.0000006	0.0000001
Exposed Veg. Intake/Meteorological Location	0.000004	0.00000004	0.0002	5.2E-10	0.00007	1.4E-09	0.00000008	0.00002	0.000003	0.0000003	0.0000001
Exposed Veg. Intake/ Distance to Receptor											
Exposed Veg. Intake/WMU Area	0.00001	0.0000001	0.0009	1.8E-09	0.0002	5.1E-09	0.0000003	0.0001	0.00001	0.000001	0.0000004
Root Veg. Intake/Fruit Intake	0.000003	0.00000005	0.0002	4.5E-10	0.00006	1.2E-09	0.00000008	0.00003	0.000002	0.0000003	0.0000001
Root Veg. Intake/Waste Concentration	0.000006	0.00000005	0.0004	3.4E-09	0.0004	2.1E-09	0.0000002	0.00005	0.00001	0.0000003	0.000003
Root Veg. Intake/Adult Soil Intake	0.000005	0.00000003	0.0004	8.0E-10	0.00008	2.5E-09	0.0000001	0.00003	0.000005	0.0000006	0.0000001
Root Veg. Intake/ Meteorological Location	0.000003	0.00000002	0.0002	4.7E-10	0.00005	1.4E-09	0.00000008	0.00002	0.000003	0.0000003	0.00000009
Root Veg. Intake/ Distance to Receptor	0.000005	0.00000007	0.0004	7.9E-10	0.00006	2.2E-09	0.0000002	0.00002	0.000005	0.0000005	0.0000002
Root Intake/WMU Area	0.00001	0.00000008	0.0009	1.7E-09	0.0001	5.0E-09	0.0000002	0.00006	0.00001	0.000001	0.0000003
Fruit Intake/Waste Concentration	0.000007	0.0000001	0.0004	4.0E-09	0.0006	2.2E-09	0.0000003	0.0001	0.00001	0.0000004	0.000004
Fruit Intake/Adult Soil Intake	0.000006	0.00000006	0.0004	8.7E-10	0.0001	2.5E-09	0.0000001	0.00004	0.000005	0.0000006	0.0000001
Fruit Intake/ Meteorological Location	0.000004	0.00000005	0.0002	5.5E-10	0.00007	1.5E-09	0.00000009	0.00003	0.000003	0.0000003	0.0000001
Fruit Intake/ Distance to Receptor	0.000006	0.0000002	0.0005	1.0E-09	0.0001	2.5E-09	0.0000003	0.00004	0.000007	0.0000006	0.0000003
Fruit Intake/ WMU Area	0.00001	0.0000002	0.0009	2.0E-09	0.0002	5.3E-09	0.0000003	0.0001	0.00001	0.000001	0.0000004
Waste Concentration/ Adult Soil Intake	0.00001	0.00000007	0.0009	7.1E-09	0.0009	4.6E-09	0.0000003	0.00009	0.00002	0.0000007	0.000007
Waste Concentration/ Meteorological Location	0.000008	0.00000005	0.0005	4.1E-09	0.0005	2.6E-09	0.0000002	0.00006	0.00001	0.0000004	0.000004
Waste Concentration/ Distance to Receptor	0.00001	0.0000002	0.0008	7.0E-09	0.0007	4.2E-09	0.0000004	0.00009	0.00002	0.0000006	0.000009

Table H1-4d Home Gardener Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Waste Concentration/ WMU Area	0.00003	0.0000002	0.002	1.5E-08	0.002	9.2E-09	0.0000008	0.0002	0.00005	0.000001	0.00001
Adult Soil Intake/ Meteorological Location	0.000006	0.00000003	0.0005	9.9E-10	0.00009	3.0E-09	0.0000001	0.00003	0.000006	0.0000007	0.0000002
Adult Soil Intake/ Distance to Receptor	0.00001	0.00000009	0.0009	1.6E-09	0.0001	4.8E-09	0.0000003	0.00004	0.00001	0.000001	0.0000004
Adult Soil Intake/ WMU Area	0.00002	0.0000001	0.002	3.5E-09	0.0003	1.1E-08	0.0000005	0.0001	0.00002	0.000002	0.0000006
Meteorological Location/Distance to Receptor	0.000005	0.00000006	0.0005	9.7E-10	0.00008	2.7E-09	0.0000001	0.00003	0.000006	0.0000006	0.0000002
Meteorological Location/WMU Area	0.00001	0.00000008	0.001	2.0E-09	0.0003	6.0E-09	0.0000003	0.00007	0.00001	0.000001	0.0000004
Distance to Receptor/WMU Area	0.000006	0.0000001	0.0004	8.7E-10	0.00007	2.4E-09	0.0000002	0.00003	0.000006	0.0000006	0.0000002

Table H1-4e Fisher Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.00000005	0.000002	0.000007	4.4E-11	0.00000008	3.4E-11	0.0000004	0.0000001	0.0000007	0.00000001	0.0000004
Single High-end Parameter											
Long Exposure	0.00000005	0.000002	0.000007	4.0E-10	0.00000008	3.1E-10	0.0000004	0.0000001	0.0000007	0.00000001	0.0000004
Fish Intake	0.00000005	0.000002	0.00002	4.9E-11	0.00000008	5.3E-11	0.0000004	0.0000006	0.0000007	0.00000001	0.000001
Waste Concentration	0.0000001	0.000004	0.00001	3.9E-10	0.0000008	6.4E-11	0.000001	0.0000006	0.000003	0.00000002	0.00002
Meteorological Location	0.000000008	0.00000009	0.000001	4.2E-12	0.00000003	5.1E-12	0.00000002	0.00000004	0.00000005	0.000000002	0.00000002
Distance to Receptor	0.00000007	0.000002	0.00001	5.3E-11	0.0000001	4.8E-11	0.0000005	0.0000002	0.0000007	0.00000002	0.0000004
WMU Area	0.0000002	0.000008	0.00003	2.0E-10	0.0000003	1.5E-10	0.000002	0.0000006	0.000003	0.00000006	0.000002
Double High-end Parameters											
Fish Intake/Long Exposure	0.00000005	0.000002	0.00002	4.4E-10	0.00000008	4.8E-10	0.0000004	0.0000006	0.0000007	0.00000001	0.000001
Waste Concentration/Long Exposure	0.0000001	0.000004	0.00001	3.5E-09	0.0000008	5.8E-10	0.000001	0.0000006	0.000003	0.00000002	0.00002
Meteorological Location/Long Exposure	0.000000008	0.00000009	0.000001	3.8E-11	0.00000003	4.6E-11	0.00000002	0.00000004	0.00000005	0.000000002	0.00000002
Distance to Receptor/Long Exposure	0.00000007	0.000002	0.00001	4.8E-10	0.0000001	4.4E-10	0.0000005	0.0000002	0.0000007	0.00000002	0.0000004
WMU Area/Long Exposure	0.0000002	0.000008	0.00003	1.8E-09	0.0000003	1.4E-09	0.000002	0.0000006	0.000003	0.00000006	0.000002
Fish Intake/Waste Concentration	0.0000001	0.000004	0.00004	4.3E-10	0.0000008	9.8E-11	0.000001	0.000002	0.000003	0.00000002	0.00005
Fish Intake/Meteorological Location	0.000000008	0.00000009	0.000003	4.6E-12	0.00000003	7.9E-12	0.00000002	0.0000001	0.00000005	0.000000002	0.00000006
Fish Intake/Distance to Receptor	0.00000007	0.000002	0.00003	5.9E-11	0.0000001	7.4E-11	0.0000005	0.0000009	0.0000007	0.00000002	0.000001
Fish Intake/WMU Area	0.0000002	0.000008	0.00008	2.2E-10	0.0000003	2.3E-10	0.000002	0.000002	0.000003	0.00000006	0.000005
Waste Concentration/Meteorological Location	0.00000002	0.0000002	0.000003	3.7E-11	0.0000003	9.5E-12	0.00000007	0.0000001	0.0000002	0.000000002	0.000001
Waste Concentration/Distance to Receptor	0.0000002	0.000004	0.00003	4.7E-10	0.000001	8.9E-11	0.000001	0.0000009	0.000004	0.00000002	0.00002
Waste Concentration/WMU Area	0.0000006	0.00002	0.00007	1.7E-09	0.000004	2.8E-10	0.000006	0.000002	0.00001	0.00000008	0.00009
Meteorological Location/Distance to Receptor	0.00000003	0.00000009	0.000003	1.1E-11	0.00000009	1.5E-11	0.00000003	0.0000001	0.0000001	0.000000005	0.00000003
Meteorological Location/WMU Area	0.00000004	0.0000004	0.000004	1.8E-11	0.0000001	2.2E-11	0.0000001	0.0000001	0.0000002	0.000000007	0.0000001
Distance to Receptor/WMU Area	0.0000001	0.000002	0.00001	6.9E-11	0.0000002	7.2E-11	0.0000005	0.0000004	0.0000009	0.00000003	0.0000005

Table H1-5a Farmer Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in Offsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.000004	0.000003	0.0003	5.9E-09	0.00009	1.0E-09	0.00000005	0.00005	0.000003	0.0000004	0.0000007
Single High-end Parameter											
Long Exposure	0.000004	0.000003	0.0003	2.4E-08	0.00009	4.2E-09	0.00000005	0.00005	0.000003	0.0000004	0.0000007
Beef intake	0.00001	0.000003	0.002	7.2E-09	0.0001	2.1E-09	0.00000005	0.00005	0.00001	0.000002	0.0000008
Dairy Intake	0.000009	0.00001	0.0006	1.9E-08	0.0001	1.0E-09	0.00000005	0.00005	0.000009	0.000001	0.000002
Exposed Veg. Intake	0.000006	0.000003	0.0004	6.6E-09	0.0002	1.7E-09	0.00000008	0.0001	0.000004	0.0000005	0.0000008
Root Veg. Intake	0.000005	0.000003	0.0004	6.4E-09	0.0001	1.4E-09	0.00000005	0.00008	0.000004	0.0000004	0.0000008
Fruit Intake	0.000008	0.000003	0.0004	7.6E-09	0.0002	2.8E-09	0.0000002	0.0001	0.000005	0.0000006	0.0000009
Waste Concentration	0.00001	0.000006	0.0007	5.2E-08	0.001	2.0E-09	0.0000001	0.0002	0.00002	0.0000006	0.00003
Adult Soil Intake	0.000005	0.000003	0.0004	6.0E-09	0.00009	1.4E-09	0.00000006	0.00005	0.000004	0.0000004	0.0000007
Meteorological Location	0.000005	0.000002	0.0003	6.5E-09	0.0001	1.3E-09	0.00000004	0.00007	0.000004	0.0000005	0.0000006
Distance to Receptor	0.000007	0.00001	0.001	1.7E-08	0.0001	2.1E-09	0.0000003	0.00007	0.00001	0.000001	0.000003
WMU Area	0.00005	0.00002	0.002	5.2E-08	0.001	1.1E-08	0.0000003	0.0005	0.00002	0.000004	0.000004
Double High-end Parameters											
Beef Intake/ Long Exposure	0.00001	0.000003	0.002	2.9E-08	0.0001	8.3E-09	0.00000005	0.00005	0.00001	0.000002	0.0000008
Dairy Intake/Long Exposure	0.000009	0.00001	0.0006	7.6E-08	0.0001	4.2E-09	0.00000005	0.00005	0.000009	0.000001	0.000002
Exposed Veg. Intake/ Long Exposure	0.000006	0.000003	0.0004	2.6E-08	0.0002	6.8E-09	0.00000008	0.0001	0.000004	0.0000005	0.0000008
Root Veg. Intake/Long Exposure	0.000005	0.000003	0.0004	2.6E-08	0.0001	5.4E-09	0.00000005	0.00008	0.000004	0.0000004	0.0000008
Fruit Intake/ Long Exposure	0.000008	0.000003	0.0004	3.0E-08	0.0002	1.1E-08	0.0000002	0.0001	0.000005	0.0000006	0.0000009
Waste Concentration/Long Exposure	0.00001	0.000006	0.0007	2.1E-07	0.001	7.8E-09	0.0000001	0.0002	0.00002	0.0000006	0.00003
Adult Soil Intake/Long Exposure	0.000005	0.000003	0.0004	2.4E-08	0.00009	5.5E-09	0.00000006	0.00005	0.000004	0.0000004	0.0000007
Meteorlogical Location/Long Exposure	0.000005	0.000002	0.0003	2.6E-08	0.0001	5.0E-09	0.00000004	0.00007	0.000004	0.0000005	0.0000006
Distance to Receptor/Long Exposure	0.000007	0.00001	0.001	6.7E-08	0.0001	8.5E-09	0.0000003	0.00007	0.00001	0.000001	0.000003
WMU Area/Long Exposure	0.00005	0.00002	0.002	2.1E-07	0.001	4.3E-08	0.0000003	0.0005	0.00002	0.000004	0.000004
Beef Intake/ Dairy Intake	0.00002	0.00001	0.002	2.0E-08	0.0001	2.1E-09	0.00000005	0.00005	0.00002	0.000003	0.000002
Beef Intake/ Exposed Veg. Intake	0.00002	0.000003	0.002	7.9E-09	0.0002	2.7E-09	0.00000008	0.0001	0.00001	0.000002	0.0000008
Beef Intake/Root Vegetable Intake	0.00001	0.000003	0.002	7.7E-09	0.0001	2.4E-09	0.00000005	0.00008	0.00001	0.000002	0.0000009
Beef Intake/Fruit Intake	0.00002	0.000004	0.002	8.9E-09	0.0002	3.8E-09	0.0000002	0.0001	0.00001	0.000003	0.0000009
Beef Intake/ Waste Concentration	0.00004	0.000007	0.005	6.4E-08	0.001	3.9E-09	0.0000001	0.0002	0.00005	0.000003	0.00004
Beef Intake/Adult Soil Intake	0.00001	0.000003	0.002	7.3E-09	0.0001	2.4E-09	0.00000006	0.00005	0.00001	0.000002	0.0000008
Beef Intake/Meteorological Location	0.00001	0.000002	0.003	7.9E-09	0.0001	2.4E-09	0.00000004	0.00007	0.00001	0.000002	0.0000007
Beef Intake/Distance to Receptor	0.00003	0.00001	0.007	2.1E-08	0.0001	4.9E-09	0.0000003	0.00007	0.00004	0.000007	0.000004
Beef Intake/WMU Area	0.0001	0.00002	0.02	6.4E-08	0.001	2.0E-08	0.0000003	0.0005	0.00007	0.00002	0.000004
Dairy Intake/Exposed Vegetable Intake	0.00001	0.00001	0.0007	2.0E-08	0.0002	1.7E-09	0.00000008	0.0001	0.00001	0.000001	0.000002
Dairy Intake/Root Vegetable Intake	0.00001	0.00001	0.0007	1.9E-08	0.0002	1.4E-09	0.00000005	0.00008	0.00001	0.000001	0.000002
Dairy Intake/Fruit Intake	0.00001	0.00001	0.0007	2.1E-08	0.0003	2.8E-09	0.0000002	0.0001	0.00001	0.000001	0.000002
Dairy Intake/Waste Concentration	0.00003	0.00002	0.001	1.7E-07	0.001	2.0E-09	0.0000001	0.0002	0.00005	0.000001	0.0001
Dairy Intake/Adult Soil Intake	0.00001	0.00001	0.0007	1.9E-08	0.0001	1.4E-09	0.00000006	0.00005	0.00001	0.000001	0.000002
Dairy Intake/ Meteorological Location	0.00001	0.000008	0.0006	2.0E-08	0.0002	1.3E-09	0.00000004	0.00007	0.000009	0.000001	0.000002

Table H1-5a Farmer Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in Offsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Dairy Intake/Distance to Receptor	0.00001	0.00005	0.002	5.6E-08	0.0002	2.1E-09	0.0000003	0.00007	0.00004	0.000004	0.00001
Dairy Intake/ WMU Area	0.0001	0.00006	0.004	1.6E-07	0.002	1.1E-08	0.0000003	0.0005	0.00006	0.000009	0.00001
Exposed Veg. Intake/ Root Veg. Intake	0.000007	0.000003	0.0004	7.1E-09	0.0002	2.0E-09	0.00000008	0.0001	0.000005	0.0000005	0.0000008
Exposed Veg. Intake/ Fruit Intake	0.000009	0.000003	0.0004	8.3E-09	0.0003	3.4E-09	0.0000002	0.0002	0.000006	0.0000007	0.0000009
Exposed Veg. Intake/Waste Concentration	0.00001	0.000006	0.0007	5.9E-08	0.002	3.2E-09	0.0000002	0.0004	0.00002	0.0000007	0.00004
Exposed Veg. Intake/Adult Soil Intake	0.000006	0.000003	0.0004	6.7E-09	0.0002	2.0E-09	0.00000009	0.0001	0.000004	0.0000005	0.0000008
Exposed Veg. Intake/Meteorological Location	0.000006	0.000002	0.0004	7.3E-09	0.0002	2.1E-09	0.00000007	0.0001	0.000004	0.0000006	0.0000006
Exposed Veg. Intake/Distance to Receptor	0.000009	0.00001	0.001	1.8E-08	0.0002	3.4E-09	0.0000004	0.0001	0.00002	0.000001	0.000004
Exposed Veg. Intake/WMU Area	0.00006	0.00002	0.002	6.0E-08	0.002	1.8E-08	0.0000005	0.001	0.00003	0.000005	0.000004
Root Veg. Intake/Fruit Intake	0.000008	0.000003	0.0004	8.1E-09	0.0003	3.1E-09	0.0000002	0.0002	0.000006	0.0000006	0.0000009
Root Veg. Intake/Waste Concentration	0.00001	0.000006	0.0007	5.7E-08	0.001	2.5E-09	0.0000001	0.0004	0.00002	0.0000006	0.00004
Root Veg. Intake/Adult Soil Intake	0.000005	0.000003	0.0004	6.5E-09	0.0001	1.7E-09	0.00000006	0.00008	0.000004	0.0000004	0.0000008
Root Veg. Intake/Meteorological Location	0.000006	0.000002	0.0004	7.1E-09	0.0002	1.7E-09	0.00000004	0.0001	0.000004	0.0000005	0.0000007
Root Veg. Intake/Distance to Receptor	0.000009	0.00001	0.001	1.8E-08	0.0002	2.5E-09	0.0000003	0.0001	0.00002	0.000001	0.000003
Root Veg. Intake/WMU Area	0.00006	0.00002	0.002	5.8E-08	0.002	1.4E-08	0.0000003	0.0009	0.00003	0.000004	0.000005
Fruit Intake/Waste Concentration	0.00002	0.000007	0.0008	6.8E-08	0.003	5.1E-09	0.0000006	0.0007	0.00003	0.000001	0.00004
Fruit Intake/Adult Soil Intake	0.000008	0.000003	0.0004	7.7E-09	0.0002	3.1E-09	0.0000002	0.0001	0.000005	0.0000007	0.0000009
Fruit Intake/Meteorological Location	0.000009	0.000002	0.0004	8.5E-09	0.0004	3.2E-09	0.0000001	0.0002	0.000005	0.0000009	0.0000008
Fruit Intake/Distance to Receptor	0.00001	0.00001	0.001	2.1E-08	0.0004	6.3E-09	0.000001	0.0002	0.00002	0.000002	0.000004
Fruit Intake/WMU Area	0.00008	0.00002	0.003	7.0E-08	0.004	2.7E-08	0.000001	0.002	0.00004	0.000007	0.000004
Waste Concentration/Adult Soil Intake	0.00001	0.000006	0.0007	5.3E-08	0.001	2.6E-09	0.0000002	0.0002	0.00002	0.0000007	0.00004
Waste Concentration/Meteorological Location	0.00001	0.000005	0.0007	5.8E-08	0.001	2.3E-09	0.0000001	0.0003	0.00002	0.0000007	0.00002
Waste Concentration/Distance to Receptor	0.00002	0.00003	0.002	1.5E-07	0.001	4.0E-09	0.0000008	0.0003	0.00007	0.000002	0.0002
Waste Concentration/WMU Area	0.0001	0.00003	0.006	4.7E-07	0.01	2.0E-08	0.0000008	0.002	0.0001	0.000005	0.0002
Adult Soil Intake/Meteorological Location	0.000005	0.000002	0.0004	6.6E-09	0.0001	1.7E-09	0.00000005	0.00007	0.000004	0.0000006	0.0000006
Adult Soil Intake/Distance to Receptor	0.000007	0.00001	0.001	1.7E-08	0.0001	2.6E-09	0.0000003	0.00007	0.00002	0.000001	0.000003
Adult Soil Intake/WMU Area	0.00005	0.00002	0.002	5.4E-08	0.001	1.4E-08	0.0000003	0.0005	0.00002	0.000004	0.000004
Meteorological Location/Distance to Receptor	0.00001	0.00001	0.0009	1.7E-08	0.0002	2.5E-09	0.0000002	0.00009	0.00001	0.000001	0.000003
Meteorological Location/WMU Area	0.00005	0.00001	0.003	6.2E-08	0.001	1.3E-08	0.0000003	0.0007	0.00002	0.000005	0.000004
Distance to Receptor/WMU Area	0.00001	0.00003	0.002	3.4E-08	0.0001	3.7E-09	0.0000006	0.00008	0.00003	0.000003	0.000008

Table H1-5b Child of Farmer Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in Offsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.0002	0.0000039	0.021	7.3E-08	0.0031	2.2E-07	0.000006	0.00093	0.00021	0.000031	0.0000078
Single High-end Parameter											
Long Exposure	0.0002	0.0000039	0.021	9.1E-08	0.0031	2.5E-07	0.000006	0.00093	0.00021	0.000031	0.0000078
Beef intake	0.00021	0.000004	0.021	7.3E-08	0.0031	2.2E-07	0.000006	0.00093	0.00021	0.000031	0.0000078
Dairy Intake	0.00021	0.0000089	0.021	7.9E-08	0.0031	2.2E-07	0.000006	0.00093	0.00021	0.000031	0.0000091
Exposed Veg. Intake	0.00021	0.000004	0.021	7.3E-08	0.0031	2.2E-07	0.0000061	0.00096	0.00021	0.000031	0.0000078
Root Veg. Intake	0.0002	0.0000039	0.021	7.3E-08	0.0031	2.2E-07	0.000006	0.00093	0.00021	0.000031	0.0000078
Fruit Intake	0.00021	0.0000042	0.021	7.4E-08	0.0032	2.2E-07	0.0000062	0.001	0.00021	0.000031	0.0000079
Waste Concentration	0.00061	0.0000093	0.041	6.5E-07	0.041	4.0E-07	0.00002	0.0031	0.001	0.000031	0.00033
Adult Soil Intake	0.0002	0.0000039	0.021	7.5E-08	0.0031	2.2E-07	0.000006	0.00093	0.00021	0.000031	0.0000078
Child Soil Intake	0.0006	0.0000051	0.051	1.8E-07	0.0091	5.5E-07	0.00001	0.002	0.00061	0.000071	0.000021
Meteorological Location	0.00031	0.0000041	0.031	9.0E-08	0.0041	2.6E-07	0.000007	0.001	0.0003	0.000031	0.0000086
Distance to Receptor	0.00051	0.000023	0.042	1.5E-07	0.0061	4.1E-07	0.00001	0.002	0.00052	0.000052	0.000014
WMU Area	0.002	0.000027	0.21	5.5E-07	0.031	1.6E-06	0.00004	0.0073	0.002	0.00021	0.000054
Double High-end Parameters											
Beef Intake/ Long Exposure	0.00021	0.000004	0.021	9.1E-08	0.0031	2.5E-07	0.000006	0.00093	0.00021	0.000031	0.0000078
Dairy Intake/Long Exposure	0.00021	0.0000089	0.021	1.0E-07	0.0031	2.5E-07	0.000006	0.00093	0.00021	0.000031	0.0000091
Exposed Veg. Intake/ Long Exposure	0.00021	0.000004	0.021	9.1E-08	0.0031	2.5E-07	0.0000061	0.00096	0.00021	0.000031	0.0000078
Root Veg. Intake/Long Exposure	0.0002	0.0000039	0.021	9.1E-08	0.0031	2.5E-07	0.000006	0.00093	0.00021	0.000031	0.0000078
Fruit Intake/ Long Exposure	0.00021	0.0000042	0.021	9.4E-08	0.0032	2.5E-07	0.0000062	0.001	0.00021	0.000031	0.0000079
Waste Concentration/Long Exposure	0.00061	0.0000093	0.041	8.1E-07	0.041	4.7E-07	0.00002	0.0031	0.001	0.000031	0.00033
Adult Soil Intake/Long Exposure	0.0002	0.0000039	0.021	1.1E-07	0.0031	3.0E-07	0.000006	0.00093	0.00021	0.000031	0.0000078
Child Soil Intake/Long Exposure	0.0006	0.0000051	0.051	2.0E-07	0.0091	5.9E-07	0.00001	0.002	0.00061	0.000071	0.000021
Meteorological Location/Long Exposure	0.00031	0.0000041	0.031	1.1E-07	0.0041	3.1E-07	0.000007	0.001	0.0003	0.000031	0.0000086
Distance to Receptor/Long Exposure	0.00051	0.000023	0.042	1.9E-07	0.0061	4.8E-07	0.00001	0.002	0.00052	0.000052	0.000014
WMU Area/Long Exposure	0.002	0.000027	0.21	6.9E-07	0.031	1.9E-06	0.00004	0.0073	0.002	0.00021	0.000054
Beef Intake/ Dairy Intake	0.00021	0.000009	0.021	7.9E-08	0.0031	2.2E-07	0.000006	0.00093	0.00021	0.000032	0.0000091
Beef Intake/ Exposed Veg. Intake	0.00021	0.0000041	0.021	7.4E-08	0.0031	2.2E-07	0.0000061	0.00096	0.00021	0.000031	0.0000078
Beef Intake/Root Vegetable Intake	0.00021	0.000004	0.021	7.3E-08	0.0031	2.2E-07	0.000006	0.00093	0.00021	0.000031	0.0000078
Beef Intake/Fruit Intake	0.00021	0.0000043	0.021	7.5E-08	0.0032	2.2E-07	0.0000062	0.001	0.00021	0.000032	0.000008
Beef Intake/Waste Concentration	0.00062	0.0000095	0.043	6.5E-07	0.041	4.0E-07	0.00002	0.0031	0.001	0.000031	0.00033
Beef Intake/Adult Soil Intake	0.00021	0.000004	0.021	7.5E-08	0.0031	2.2E-07	0.000006	0.00093	0.00021	0.000031	0.0000078
Beef Intake/Child Soil Intake	0.00061	0.0000052	0.051	1.8E-07	0.0091	5.5E-07	0.00001	0.002	0.00061	0.000071	0.000021
Beef Intake/Meteorological Location	0.00031	0.0000042	0.031	9.0E-08	0.0041	2.6E-07	0.000007	0.001	0.00031	0.000031	0.0000087
Beef Intake/Distance to Receptor	0.00052	0.000023	0.044	1.5E-07	0.0061	4.1E-07	0.00001	0.002	0.00053	0.000055	0.000014
Beef Intake/WMU Area	0.0021	0.000027	0.21	5.6E-07	0.031	1.6E-06	0.00004	0.0073	0.0021	0.00021	0.000055
Dairy Intake/Exposed Vegetable Intake	0.00021	0.000009	0.021	7.9E-08	0.0031	2.2E-07	0.0000061	0.00096	0.00021	0.000031	0.0000091
Dairy Intake/Root Vegetable Intake	0.00021	0.0000089	0.021	7.9E-08	0.0031	2.2E-07	0.000006	0.00093	0.00021	0.000031	0.0000091
Dairy Intake/Fruit Intake	0.00021	0.0000092	0.021	8.0E-08	0.0033	2.2E-07	0.0000062	0.001	0.00021	0.000031	0.0000092
Dairy Intake/Waste Concentration	0.00062	0.000022	0.042	7.0E-07	0.041	4.0E-07	0.00002	0.0031	0.001	0.000031	0.00038

Table H1-5b Child of Farmer Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in Offsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Dairy Intake/ Adult Soil Intake	0.00021	0.0000089	0.021	8.0E-08	0.0031	2.2E-07	0.000006	0.00093	0.00021	0.000031	0.0000091
Dairy Intake/ Child Soil Intake	0.00061	0.00001	0.051	1.9E-07	0.0091	5.5E-07	0.00001	0.002	0.00061	0.000071	0.000022
Dairy Intake/ Meteorological Location	0.00031	0.0000071	0.031	9.6E-08	0.0041	2.6E-07	0.000007	0.001	0.00031	0.000031	0.000009
Dairy Intake/Distance to Receptor	0.00052	0.000043	0.043	1.7E-07	0.0061	4.1E-07	0.00001	0.002	0.00054	0.000053	0.000019
Dairy Intake/WMU Area	0.0021	0.000047	0.21	6.0E-07	0.031	1.6E-06	0.00004	0.0073	0.0021	0.00021	0.000059
Exposed Veg. Intake/ Root Veg. Intake	0.00021	0.000004	0.021	7.3E-08	0.0031	2.2E-07	0.0000061	0.00096	0.00021	0.000031	0.0000078
Exposed Veg. Intake/ Fruit Intake	0.00021	0.0000042	0.021	7.5E-08	0.0033	2.2E-07	0.0000062	0.001	0.00021	0.000031	0.000008
Exposed Veg. Intake/Waste Concentration	0.00062	0.0000094	0.041	6.5E-07	0.041	4.0E-07	0.00002	0.0033	0.001	0.000031	0.00033
Exposed Veg. Intake/Adult Soil Intake	0.00021	0.000004	0.021	7.5E-08	0.0031	2.2E-07	0.0000061	0.00096	0.00021	0.000031	0.0000078
Exposed Veg. Intake/Child Soil Intake	0.00061	0.0000052	0.051	1.8E-07	0.0091	5.5E-07	0.00001	0.0021	0.00061	0.000071	0.000021
Exposed Veg. Intake/Meteorological Location	0.00031	0.0000042	0.031	9.0E-08	0.0041	2.6E-07	0.000007	0.0011	0.0003	0.000031	0.0000087
Exposed Veg. Intake/Distance to Receptor	0.00051	0.000023	0.042	1.5E-07	0.0062	4.1E-07	0.00001	0.0021	0.00052	0.000052	0.000014
Exposed Veg. Intake/WMU Area	0.0021	0.000027	0.21	5.6E-07	0.031	1.6E-06	0.00004	0.0077	0.002	0.00021	0.000055
Root Veg. Intake/Fruit Intake	0.00021	0.0000042	0.021	7.4E-08	0.0032	2.2E-07	0.0000062	0.001	0.00021	0.000031	0.0000079
Root Veg. Intake/Waste Concentration	0.00061	0.0000093	0.041	6.5E-07	0.041	4.0E-07	0.00002	0.0031	0.001	0.000031	0.00033
Root Veg. Intake/Adult Soil Intake	0.0002	0.0000039	0.021	7.5E-08	0.0031	2.2E-07	0.000006	0.00093	0.00021	0.000031	0.0000078
Root Veg. Intake/Child Soil Intake	0.0006	0.0000051	0.051	1.8E-07	0.0091	5.5E-07	0.00001	0.002	0.00061	0.000071	0.000021
Root Veg. Intake/Meteorological Location	0.00031	0.0000041	0.031	9.0E-08	0.0041	2.6E-07	0.000007	0.001	0.0003	0.000031	0.0000087
Root Veg. Intake/Distance to Receptor	0.00051	0.000023	0.042	1.5E-07	0.0061	4.1E-07	0.00001	0.002	0.00052	0.000052	0.000014
Root Veg. Intake/WMU Area	0.002	0.000027	0.21	5.5E-07	0.031	1.6E-06	0.00004	0.0073	0.002	0.00021	0.000054
Fruit Intake/Waste Concentration	0.00062	0.0000098	0.041	6.6E-07	0.042	4.1E-07	0.000021	0.0035	0.001	0.000031	0.00034
Fruit Intake/Adult Soil Intake	0.00021	0.0000042	0.021	7.6E-08	0.0032	2.2E-07	0.0000062	0.001	0.00021	0.000031	0.0000079
Fruit Intake/Child Soil Intake	0.00061	0.0000054	0.051	1.8E-07	0.0092	5.6E-07	0.00001	0.0021	0.00061	0.000071	0.000021
Fruit Intake/Meteorological Location	0.00031	0.0000044	0.031	9.1E-08	0.0043	2.6E-07	0.0000071	0.0012	0.00031	0.000031	0.0000088
Fruit Intake/Distance to Receptor	0.00051	0.000023	0.043	1.5E-07	0.0063	4.1E-07	0.000011	0.0022	0.00053	0.000052	0.000015
Fruit Intake/WMU Area	0.0021	0.000029	0.21	5.7E-07	0.033	1.6E-06	0.000041	0.0081	0.002	0.00021	0.000055
Waste Concentration/ Adult Soil Intake	0.00061	0.0000093	0.041	6.6E-07	0.041	4.1E-07	0.00002	0.0031	0.001	0.000031	0.00033
Waste Concentration/ Child Soil Intake	0.002	0.000012	0.1	*1.6E-06*	0.1	1.0E-06	0.00004	0.0091	0.003	0.000091	0.00083
Waste Concentration/Meteorological Location	0.00082	0.0000082	0.051	8.0E-07	0.041	4.9E-07	0.00002	0.0041	0.001	0.000041	0.00043
Waste Concentration/Distance to Receptor	0.001	0.000035	0.094	*1.3E-06*	0.061	7.7E-07	0.00003	0.0061	0.0021	0.000063	0.00091
Waste Concentration/WMU Area	0.0051	0.000052	0.31	*4.9E-06*	0.31	3.1E-06	0.0001	0.031	0.0092	0.00021	0.0022
Adult Soil Intake/Child Soil Intake	0.0006	0.0000051	0.051	1.8E-07	0.0091	5.6E-07	0.00001	0.002	0.00061	0.000071	0.000021
Adult Soil Intake/Meteorological Location	0.00031	0.0000041	0.031	9.2E-08	0.0041	2.7E-07	0.000007	0.001	0.0003	0.000031	0.0000086
Adult Soil Intake/Distance to Receptor	0.00051	0.000023	0.042	1.5E-07	0.0061	4.2E-07	0.00001	0.002	0.00052	0.000052	0.000014
Adult Soil Intake/WMU Area	0.002	0.000027	0.21	5.6E-07	0.031	1.7E-06	0.00004	0.0073	0.002	0.00021	0.000054
Child Soil Intake/ Meteorological Location	0.00081	0.0000061	0.071	2.2E-07	0.01	6.8E-07	0.00002	0.003	0.0008	0.000091	0.000021
Child Soil Intake/Distance to Receptor	0.001	0.000025	0.1	3.6E-07	0.01	1.1E-06	0.00003	0.004	0.001	0.0001	0.000044
Child Soil Intake/WMU Area	0.005	0.000041	0.41	*1.4E-06*	0.071	4.2E-06	0.0001	0.02	0.005	0.00051	0.0001
Meteorological Location/Distance to Receptor	0.00061	0.000012	0.052	1.8E-07	0.0061	5.0E-07	0.00001	0.002	0.00062	0.000062	0.000023
Meteorological Location/WMU Area	0.0021	0.000029	0.21	6.8E-07	0.031	2.0E-06	0.00005	0.0083	0.002	0.00021	0.000063

Table H1-5b Child of Farmer Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in Offsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Distance to Receptor/WMU Area	0.00052	0.000033	0.044	1.6E-07	0.0061	4.1E-07	0.00001	0.002	0.00055	0.000055	0.000019

Table H1-5c Adult Resident Individual Risk from All Ingestion Pathways for Non-utility Coal Co-Managed Wastes Managed in Offsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.000006	0.00000002	0.0005	8.6E-10	0.00008	2.7E-09	0.0000001	0.00002	0.000006	0.0000006	0.0000002
Single High-end Parameter											
Long Exposure	0.000006	0.00000002	0.0005	8.4E-09	0.00008	2.7E-08	0.0000001	0.00002	0.000006	0.0000006	0.0000002
Constituent Conc.	0.00001	0.00000004	0.001	7.7E-09	0.0009	5.1E-09	0.0000004	0.00008	0.00003	0.0000008	0.000008
Adult Soil Intake	0.00001	0.00000004	0.001	1.9E-09	0.0002	6.0E-09	0.0000003	0.00004	0.00001	0.000001	0.0000003
Meteorological Location	0.000007	0.00000002	0.0006	1.1E-09	0.00009	3.3E-09	0.0000002	0.00002	0.000007	0.0000008	0.0000002
Distance To Receptor	0.00001	0.00000004	0.0009	1.7E-09	0.0001	5.2E-09	0.0000003	0.00004	0.00001	0.000001	0.0000003
WMU Area	0.00004	0.0000001	0.004	6.5E-09	0.0006	2.1E-08	0.000001	0.0002	0.00004	0.000005	0.000001
Double High-end Parameters											
Constituent Conc./Long Exposure	0.00001	0.00000004	0.001	7.5E-08	0.0009	5.0E-08	0.0000004	0.00008	0.00003	0.0000008	0.000008
Adult Soil Intake/Long Exposure	0.00001	0.00000004	0.001	1.9E-08	0.0002	5.8E-08	0.0000003	0.00004	0.00001	0.000001	0.0000003
Meteorological Location/Long Exposure	0.000007	0.00000002	0.0006	1.0E-08	0.00009	3.2E-08	0.0000002	0.00002	0.000007	0.0000008	0.0000002
Distance to Receptor/Long Exposure	0.00001	0.00000004	0.0009	1.7E-08	0.0001	5.1E-08	0.0000003	0.00004	0.00001	0.000001	0.0000003
WMU Area/Long Exposure	0.00004	0.0000001	0.004	6.3E-08	0.0006	2.0E-07	0.000001	0.0002	0.00004	0.000005	0.000001
Waste Concentration/ Adult Soil Intake	0.00003	0.00000009	0.002	1.7E-08	0.002	1.1E-08	0.0000009	0.0002	0.00006	0.000002	0.00002
Waste Concentration/ Meteorological Location	0.00002	0.00000005	0.001	9.5E-09	0.0009	6.2E-09	0.0000005	0.00009	0.00003	0.000001	0.000009
Waste Concentration/ Distance to Receptor	0.00003	0.00000009	0.002	1.5E-08	0.001	9.6E-09	0.0000008	0.0001	0.00005	0.000001	0.00002
Waste Concentration/ WMU Area	0.0001	0.0000003	0.008	5.8E-08	0.007	3.8E-08	0.000003	0.0006	0.0002	0.000006	0.00006
Adult Soil Intake/ Meteorological Location	0.00002	0.00000005	0.001	2.3E-09	0.0002	7.3E-09	0.0000004	0.00005	0.00002	0.000002	0.0000004
Adult Soil Intake/ Distance to Receptor	0.00002	0.00000009	0.002	3.7E-09	0.0003	1.1E-08	0.0000006	0.00008	0.00002	0.000003	0.0000007
Adult Soil Intake/ WMU Area	0.0001	0.0000003	0.008	1.4E-08	0.001	4.5E-08	0.000002	0.0003	0.00009	0.00001	0.000003
Meteorological Location/Distance to Receptor	0.00001	0.00000005	0.001	2.1E-09	0.0001	6.2E-09	0.0000003	0.00004	0.00001	0.000001	0.0000004
Meteorological Location/WMU Area	0.00005	0.0000002	0.005	8.0E-09	0.0007	2.5E-08	0.000001	0.0002	0.00005	0.000006	0.000001
Distance to Receptor/WMU Area	0.00001	0.00000004	0.0009	1.7E-09	0.0001	5.2E-09	0.0000003	0.00004	0.00001	0.000001	0.0000003

Table H1-5d Home Gardener Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in Offsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Central Tendency	0.000006	0.00000005	0.0005	9.2E-10	0.0001	2.8E-09	0.0000001	0.00003	0.000006	0.0000006	0.0000002
Single High-end Parameter											
Long Exposure	0.000006	0.00000005	0.0005	9.0E-09	0.0001	2.7E-08	0.0000001	0.00003	0.000006	0.0000006	0.0000002
Exposed Veg. Intake	0.000007	0.00000008	0.0005	1.0E-09	0.0001	2.9E-09	0.0000001	0.00006	0.000006	0.0000007	0.0000002
Root Veg.Intake	0.000006	0.00000005	0.0005	9.3E-10	0.0001	2.8E-09	0.0000001	0.00003	0.000006	0.0000006	0.0000002
Fruit Intake	0.000007	0.0000001	0.0005	1.1E-09	0.0002	2.9E-09	0.0000002	0.00007	0.000007	0.0000007	0.0000003
Constituent Conc.	0.00001	0.00000009	0.001	8.2E-09	0.001	5.2E-09	0.0000004	0.0001	0.00003	0.0000008	0.000009
Adult Soil Intake	0.00001	0.00000007	0.001	2.0E-09	0.0002	6.0E-09	0.0000003	0.00005	0.00001	0.000001	0.0000003
Meteorological Location	0.000007	0.00000005	0.0006	1.1E-09	0.0001	3.4E-09	0.0000002	0.00004	0.000007	0.0000008	0.0000002
Distance To Receptor	0.00001	0.0000001	0.0009	1.8E-09	0.0001	5.3E-09	0.0000004	0.00006	0.00001	0.000001	0.0000004
WMU Area	0.00004	0.0000003	0.004	7.1E-09	0.0008	2.1E-08	0.000001	0.0003	0.00004	0.000005	0.000001
Double High-end Parameters											
Exposed Veg. Intake/Long Exposure	0.000007	0.00000008	0.0005	1.0E-08	0.0001	2.8E-08	0.0000001	0.00006	0.000006	0.0000007	0.0000002
Root Veg. Intake/Long Exposure	0.000006	0.00000005	0.0005	9.1E-09	0.0001	2.7E-08	0.0000001	0.00003	0.000006	0.0000006	0.0000002
Fruit Intake/Long Exposure	0.000007	0.0000001	0.0005	1.1E-08	0.0002	2.9E-08	0.0000002	0.00007	0.000007	0.0000007	0.0000003
Constituent Conc./Long Exposure	0.00001	0.00000009	0.001	8.0E-08	0.001	5.1E-08	0.0000004	0.0001	0.00003	0.0000008	0.000009
Adult Soil Intake/Long Exposure	0.00001	0.00000007	0.001	1.9E-08	0.0002	5.9E-08	0.0000003	0.00005	0.00001	0.000001	0.0000003
Meteorological Location/Long Exposure	0.000007	0.00000005	0.0006	1.1E-08	0.0001	3.3E-08	0.0000002	0.00004	0.000007	0.0000008	0.0000002
Distance to Receptor/Long Exposure	0.00001	0.0000001	0.0009	1.8E-08	0.0001	5.2E-08	0.0000004	0.00006	0.00001	0.000001	0.0000004
WMU Area/Long Exposure	0.00004	0.0000003	0.004	6.9E-08	0.0008	2.1E-07	0.000001	0.0003	0.00004	0.000005	0.000001
Exposed Veg. Intake/Root Veg. Intake	0.000007	0.00000008	0.0005	1.0E-09	0.0001	2.9E-09	0.0000001	0.00006	0.000006	0.0000007	0.0000002
Exposed Veg. Intake/ Fruit Intake	0.000008	0.0000002	0.0005	1.2E-09	0.0002	3.0E-09	0.0000002	0.00009	0.000007	0.0000007	0.0000003
Exposed Veg. Intake/Waste Concentration	0.00001	0.0000002	0.001	9.2E-09	0.002	5.4E-09	0.0000005	0.0002	0.00003	0.0000009	0.00001
Exposed Veg. Intake/Adult Soil Intake	0.00001	0.0000001	0.001	2.1E-09	0.0003	6.1E-09	0.0000003	0.00008	0.00001	0.000001	0.0000003
Exposed Veg. Intake/Meteorological Location	0.000008	0.00000009	0.0006	1.3E-09	0.0002	3.5E-09	0.0000002	0.00007	0.000007	0.0000009	0.0000002
Exposed Veg. Intake/ Distance to Receptor	0.00001	0.0000002	0.0009	2.0E-09	0.0002	5.5E-09	0.0000005	0.00009	0.00001	0.000001	0.0000005
Exposed Veg. Intake/WMU Area	0.00005	0.0000006	0.004	8.2E-09	0.001	2.2E-08	0.000001	0.0006	0.00004	0.000006	0.000001
Root Veg. Intake/Fruit Intake	0.000007	0.0000001	0.0005	1.1E-09	0.0002	3.0E-09	0.0000002	0.00007	0.000007	0.0000007	0.0000003
Root Veg. Intake/Waste Concentration	0.00001	0.0000001	0.001	8.3E-09	0.001	5.2E-09	0.0000004	0.0001	0.00003	0.0000008	0.000009
Root Veg. Intake/Adult Soil Intake	0.00001	0.00000007	0.001	2.0E-09	0.0002	6.0E-09	0.0000003	0.00005	0.00001	0.000001	0.0000003
Root Veg. Intake/ Meteorological Location	0.000007	0.00000005	0.0006	1.2E-09	0.0001	3.4E-09	0.0000002	0.00004	0.000007	0.0000008	0.0000002
Root Veg. Intake/ Distance to Receptor	0.00001	0.0000001	0.0009	1.8E-09	0.0001	5.3E-09	0.0000004	0.00006	0.00001	0.000001	0.0000004
Root Intake/WMU Area	0.00004	0.0000003	0.004	7.2E-09	0.0008	2.1E-08	0.000001	0.0004	0.00004	0.000005	0.000001
Fruit Intake/Waste Concentration	0.00001	0.0000003	0.001	9.8E-09	0.002	5.5E-09	0.0000006	0.0003	0.00003	0.0000009	0.00001
Fruit Intake/Adult Soil Intake	0.00001	0.0000001	0.001	2.1E-09	0.0003	6.2E-09	0.0000004	0.00009	0.00001	0.000001	0.0000004
Fruit Intake/ Meteorological Location	0.000008	0.0000001	0.0006	1.3E-09	0.0002	3.6E-09	0.0000002	0.00008	0.000008	0.0000009	0.0000003
Fruit Intake/ Distance to Receptor	0.00001	0.0000004	0.001	2.2E-09	0.0002	5.7E-09	0.0000006	0.0001	0.00001	0.000001	0.0000006
Fruit Intake/ WMU Area	0.00005	0.0000009	0.004	8.8E-09	0.001	2.3E-08	0.000001	0.0008	0.00005	0.000006	0.000001
Waste Concentration/ Adult Soil Intake	0.00003	0.0000001	0.002	1.7E-08	0.002	1.1E-08	0.0000009	0.0003	0.00006	0.000002	0.00002
Waste Concentration/ Meteorological Location	0.00002	0.0000001	0.001	1.0E-08	0.001	6.3E-09	0.0000005	0.0002	0.00003	0.000001	0.00001

Table H1-5d Home Gardener Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in Offsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Selenium
Waste Concentration/ Distance to Receptor	0.00003	0.0000002	0.002	1.6E-08	0.001	9.9E-09	0.000001	0.0002	0.00005	0.000001	0.00002
Waste Concentration/ WMU Area	0.0001	0.0000007	0.008	6.3E-08	0.01	3.9E-08	0.000003	0.001	0.0002	0.000006	0.00006
Adult Soil Intake/ Meteorological Location	0.00002	0.00000008	0.001	2.4E-09	0.0002	7.4E-09	0.0000004	0.00007	0.00002	0.000002	0.0000004
Adult Soil Intake/ Distance to Receptor	0.00002	0.0000002	0.002	3.8E-09	0.0003	1.1E-08	0.0000007	0.0001	0.00002	0.000003	0.0000008
Adult Soil Intake/ WMU Area	0.0001	0.0000005	0.008	1.5E-08	0.001	4.6E-08	0.000002	0.0004	0.00009	0.00001	0.000003
Meteorological Location/Distance to Receptor	0.00001	0.0000001	0.001	2.2E-09	0.0001	6.4E-09	0.0000004	0.00006	0.00001	0.000001	0.0000005
Meteorological Location/WMU Area	0.00006	0.0000004	0.005	8.8E-09	0.001	2.6E-08	0.000001	0.0004	0.00005	0.000006	0.000001
Distance to Receptor/WMU Area	0.00001	0.0000002	0.0009	1.9E-09	0.0001	5.4E-09	0.0000004	0.00006	0.00001	0.000001	0.0000004

Table H1-5e Fisher Individual Risk from All Ingestion Pathways for Non-utility Coal Co-managed Wastes Managed in Offsite Landfill

Parameters Set to High-end	Nickel	Thallium	Arsenic	Beryllium	Cadmium	Chromium VI	Selenium
Central Tendency	0.000000001	0.000005	2.2E-12	8.5E-12	0.0000002	0.00000001	0.0000004
Single High-end Parameter							
Long Exposure	0.000000001	0.000005	2.1E-11	8.3E-11	0.0000002	0.00000001	0.0000004
Fish Intake	0.000000004	0.00003	1.4E-11	5.4E-11	0.000001	0.00000006	0.000002
Waste Concentration	0.000000002	0.00001	2.0E-11	1.6E-11	0.0000007	0.00000005	0.00002
Meteorological Location	0.0000000001	0.0000007	2.0E-13	1.2E-12	0.00000004	0.000000001	0.00000002
Distance to Receptor	0.000000001	0.000006	2.4E-12	1.0E-11	0.0000002	0.00000001	0.0000004
WMU Area	0.000000007	0.00006	2.5E-11	9.7E-11	0.000002	0.0000001	0.000004
Double High-end Parameters							
Fish Intake/Long Exposure	0.000000004	0.00003	1.4E-10	5.3E-10	0.000001	0.00000006	0.000002
Waste Concentration/Long Exposure	0.000000002	0.00001	1.9E-10	1.5E-10	0.0000007	0.00000005	0.00002
Meteorological Location/Long Exposure	0.0000000001	0.0000007	2.0E-12	1.2E-11	0.00000004	0.000000001	0.00000002
Distance to Receptor/Long Exposure	0.000000001	0.000006	2.4E-11	9.8E-11	0.0000002	0.00000001	0.0000004
WMU Area/Long Exposure	0.000000007	0.00006	2.5E-10	9.5E-10	0.000002	0.0000001	0.000004
Fish Intake/Waste Concentration	0.00000001	0.00007	1.2E-10	1.0E-10	0.000005	0.0000003	0.0001
Fish Intake/Meteorological Location	0.000000001	0.000005	1.3E-12	7.7E-12	0.0000003	0.000000005	0.0000001
Fish Intake/Distance to Receptor	0.000000005	0.00004	1.5E-11	6.4E-11	0.000001	0.00000006	0.000002
Fish Intake/WMU Area	0.00000004	0.0004	1.6E-10	6.2E-10	0.00001	0.0000007	0.00003
Waste Concentration/Meteorological Location	0.000000000	0.000002	1.8E-12	2.2E-12	0.0000002	0.000000004	0.0000009
Waste Concentration/Distance to Receptor	0.000000002	0.00001	2.1E-11	1.9E-11	0.0000009	0.00000005	0.00002
Waste Concentration/WMU Area	0.00000002	0.0001	2.3E-10	1.8E-10	0.000008	0.0000005	0.0002
Meteorological Location/Distance to Receptor	0.0000000002	0.000001	3.6E-13	2.4E-12	0.00000008	0.000000001	0.00000002
Meteorological Location/WMU Area	0.000000001	0.000007	2.1E-12	1.2E-11	0.0000004	0.000000008	0.0000002
Distance to Receptor/WMU Area	0.000000001	0.000008	2.8E-12	1.3E-11	0.0000003	0.00000001	0.0000004

Table H1-6a Farmer Individual Risk from All Ingestion Pathways for FBC Wastes Managed in Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Central Tendency	0.000009	0.000002	0.0006	3.2E-08	0.0002	1.8E-09	0.00000005	0.00005	0.00001	0.0000004	0.00002
Single High-end Parameter											
Long Exposure	0.000009	0.000002	0.0006	1.3E-07	0.0002	7.2E-09	0.00000005	0.00005	0.00001	0.0000004	0.00002
Beef intake	0.00003	0.000002	0.004	3.9E-08	0.0002	3.5E-09	0.00000005	0.00005	0.00004	0.000002	0.00004
Dairy Intake	0.00001	0.000008	0.001	1.0E-07	0.0002	1.8E-09	0.00000005	0.00005	0.00004	0.000001	0.00006
Exposed Veg. Intake	0.00001	0.000002	0.0006	3.6E-08	0.0003	3.0E-09	0.00000009	0.0001	0.00002	0.0000005	0.00002
Root Veg. Intake	0.00001	0.000002	0.0006	3.5E-08	0.0002	2.4E-09	0.00000005	0.00008	0.00002	0.0000004	0.00002
Fruit Intake	0.00001	0.000002	0.0006	4.2E-08	0.0006	4.7E-09	0.0000002	0.0001	0.00002	0.0000007	0.00002
Waste Concentration	0.0003	0.00001	0.002	2.6E-07	0.0006	9.0E-09	0.0000001	0.0003	0.00002	0.000001	0.003
Adult Soil Intake	0.000009	0.000002	0.0006	3.2E-08	0.0002	2.4E-09	0.00000006	0.00005	0.00002	0.0000005	0.00002
Meteorological Location	0.00001	0.000002	0.0006	3.6E-08	0.0002	2.2E-09	0.00000004	0.00005	0.00001	0.0000005	0.00002
Distance to Receptor	0.00001	0.000007	0.001	6.2E-08	0.0002	2.8E-09	0.0000001	0.00005	0.00003	0.000001	0.00004
WMU Area	0.00002	0.000004	0.0009	6.0E-08	0.0004	3.5E-09	0.00000008	0.00009	0.00002	0.0000009	0.00003
Double High-end Parameters											
Beef Intake/ Long Exposure	0.00003	0.000002	0.004	1.6E-07	0.0002	1.4E-08	0.00000005	0.00005	0.00004	0.000002	0.00004
Dairy Intake/Long Exposure	0.00001	0.000008	0.001	4.0E-07	0.0002	7.2E-09	0.00000005	0.00005	0.00004	0.000001	0.00006
Exposed Veg. Intake/ Long Exposure	0.00001	0.000002	0.0006	1.4E-07	0.0003	1.2E-08	0.00000009	0.0001	0.00002	0.0000005	0.00002
Root Veg. Intake/Long Exposure	0.00001	0.000002	0.0006	1.4E-07	0.0002	9.5E-09	0.00000005	0.00008	0.00002	0.0000004	0.00002
Fruit Intake/ Long Exposure	0.00001	0.000002	0.0006	1.7E-07	0.0006	1.9E-08	0.0000002	0.0001	0.00002	0.0000007	0.00002
Waste Concentration/Long Exposure	0.0003	0.00001	0.002	***1.0E-06***	0.0006	3.6E-08	0.0000001	0.0003	0.00002	0.000001	0.003
Adult Soil Intake/Long Exposure	0.000009	0.000002	0.0006	1.3E-07	0.0002	9.6E-09	0.00000006	0.00005	0.00002	0.0000005	0.00002
Meteorlogical Location/Long Exposure	0.00001	0.000002	0.0006	1.5E-07	0.0002	8.8E-09	0.00000004	0.00005	0.00001	0.0000005	0.00002
Distance to Receptor/Long Exposure	0.00001	0.000007	0.001	2.5E-07	0.0002	1.1E-08	0.0000001	0.00005	0.00003	0.000001	0.00004
WMU Area/Long Exposure	0.00002	0.000004	0.0009	2.4E-07	0.0004	1.4E-08	0.00000008	0.00009	0.00002	0.0000009	0.00003
Beef Intake/ Dairy Intake	0.00003	0.000008	0.005	1.1E-07	0.0003	3.5E-09	0.00000005	0.00005	0.00006	0.000003	0.00008
Beef Intake/ Exposed Veg. Intake	0.00003	0.000002	0.004	4.3E-08	0.0003	4.6E-09	0.00000009	0.0001	0.00004	0.000002	0.00004
Beef Intake/Root Vegetable Intake	0.00003	0.000002	0.004	4.2E-08	0.0002	4.1E-09	0.00000005	0.00008	0.00004	0.000002	0.00004
Beef Intake/Fruit Intake	0.00003	0.000002	0.004	4.9E-08	0.0006	6.4E-09	0.0000002	0.0001	0.00005	0.000003	0.00004
Beef Intake/ Waste Concentration	0.0009	0.00001	0.02	3.2E-07	0.0006	1.7E-08	0.0000001	0.0003	0.00007	0.000007	0.005
Beef Intake/Adult Soil Intake	0.00003	0.000002	0.004	4.0E-08	0.0002	4.1E-09	0.00000006	0.00005	0.00004	0.000002	0.00004
Beef Intake/Meteorological Location	0.00003	0.000002	0.005	4.4E-08	0.0002	4.1E-09	0.00000004	0.00005	0.00004	0.000002	0.00004
Beef Intake/Distance to Receptor	0.00004	0.000008	0.009	7.7E-08	0.0002	6.0E-09	0.0000001	0.00005	0.0001	0.000005	0.00007
Beef Intake/WMU Area	0.00005	0.000005	0.008	7.3E-08	0.0004	6.7E-09	0.00000008	0.00009	0.00007	0.000005	0.00006
Dairy Intake/Exposed Vegetable Intake	0.00002	0.000008	0.001	1.1E-07	0.0004	3.0E-09	0.00000009	0.0001	0.00004	0.000001	0.00006
Dairy Intake/Root Vegetable Intake	0.00002	0.000008	0.001	1.0E-07	0.0003	2.4E-09	0.00000005	0.00008	0.00004	0.000001	0.00006
Dairy Intake/Fruit Intake	0.00002	0.000008	0.001	1.1E-07	0.0006	4.7E-09	0.0000002	0.0001	0.00004	0.000001	0.00006
Dairy Intake/Waste Concentration	0.0007	0.00005	0.004	8.2E-07	0.0008	9.0E-09	0.0000001	0.0003	0.00006	0.000003	0.007
Dairy Intake/Adult Soil Intake	0.00002	0.000008	0.001	1.0E-07	0.0003	2.4E-09	0.00000006	0.00005	0.00004	0.000001	0.00006
Dairy Intake/ Meteorological Location	0.00003	0.000007	0.001	1.1E-07	0.0003	2.2E-09	0.00000004	0.00005	0.00004	0.000001	0.00006
Dairy Intake/Distance to Receptor	0.00003	0.00002	0.002	2.0E-07	0.0003	2.8E-09	0.0000001	0.00005	0.0001	0.000002	0.0001

Table H1-6a Farmer Individual Risk from All Ingestion Pathways for FBC Wastes Managed in Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Dairy Intake/ WMU Area	0.00004	0.00001	0.002	1.9E-07	0.0005	3.5E-09	0.00000008	0.00009	0.00006	0.000001	0.00009
Exposed Veg. Intake/ Root Veg. Intake	0.00001	0.000002	0.0006	3.9E-08	0.0004	3.5E-09	0.00000009	0.0001	0.00002	0.0000005	0.00002
Exposed Veg. Intake/ Fruit Intake	0.00002	0.000002	0.0007	4.6E-08	0.0007	5.8E-09	0.0000002	0.0002	0.00002	0.0000007	0.00003
Exposed Veg. Intake/Waste Concentration	0.0003	0.00001	0.002	2.9E-07	0.001	1.5E-08	0.0000002	0.0007	0.00002	0.000002	0.003
Exposed Veg. Intake/Adult Soil Intake	0.00001	0.000002	0.0006	3.6E-08	0.0003	3.5E-09	0.00000009	0.0001	0.00002	0.0000005	0.00002
Exposed Veg. Intake/Meteorological Location	0.00001	0.000002	0.0006	4.1E-08	0.0004	3.6E-09	0.00000007	0.0001	0.00002	0.0000007	0.00002
Exposed Veg. Intake/Distance to Receptor	0.00002	0.000007	0.001	6.8E-08	0.0004	4.5E-09	0.0000002	0.0001	0.00004	0.000001	0.00005
Exposed Veg. Intake/WMU Area	0.00002	0.000004	0.001	6.8E-08	0.0007	5.7E-09	0.0000001	0.0002	0.00003	0.000001	0.00004
Root Veg. Intake/Fruit Intake	0.00002	0.000002	0.0006	4.5E-08	0.0006	5.2E-09	0.0000002	0.0002	0.00002	0.0000007	0.00003
Root Veg. Intake/Waste Concentration	0.0003	0.00001	0.002	2.8E-07	0.0008	1.2E-08	0.0000001	0.0006	0.00002	0.000001	0.003
Root Veg. Intake/Adult Soil Intake	0.00001	0.000002	0.0006	3.5E-08	0.0002	2.9E-09	0.00000006	0.00008	0.00002	0.0000005	0.00002
Root Veg. Intake/Meteorological Location	0.00001	0.000002	0.0006	4.0E-08	0.0003	2.9E-09	0.00000004	0.00009	0.00002	0.0000005	0.00002
Root Veg. Intake/Distance to Receptor	0.00002	0.000007	0.001	6.6E-08	0.0003	3.5E-09	0.0000001	0.00008	0.00004	0.000001	0.00005
Root Veg. Intake/WMU Area	0.00002	0.000004	0.001	6.6E-08	0.0004	4.6E-09	0.00000008	0.0002	0.00003	0.0000009	0.00004
Fruit Intake/Waste Concentration	0.0005	0.00001	0.003	3.4E-07	0.002	2.3E-08	0.0000004	0.001	0.00003	0.000002	0.004
Fruit Intake/Adult Soil Intake	0.00002	0.000002	0.0007	4.2E-08	0.0006	5.3E-09	0.0000002	0.0001	0.00002	0.0000007	0.00003
Fruit Intake/Meteorological Location	0.00002	0.000002	0.0007	4.8E-08	0.0006	5.6E-09	0.0000001	0.0002	0.00002	0.0000009	0.00002
Fruit Intake/Distance to Receptor	0.00002	0.000008	0.001	7.8E-08	0.0006	7.8E-09	0.0000006	0.0002	0.00005	0.000001	0.00006
Fruit Intake/WMU Area	0.00003	0.000005	0.001	7.9E-08	0.001	9.0E-09	0.0000003	0.0003	0.00004	0.000001	0.00005
Waste Concentration/Adult Soil Intake	0.0003	0.00001	0.002	2.6E-07	0.0006	1.2E-08	0.0000001	0.0004	0.00002	0.000001	0.003
Waste Concentration/Meteorological Location	0.0004	0.00001	0.003	3.0E-07	0.0008	1.1E-08	0.00000009	0.0005	0.00002	0.000001	0.003
Waste Concentration/Distance to Receptor	0.0004	0.00004	0.006	5.1E-07	0.0008	1.4E-08	0.0000004	0.0004	0.00006	0.000002	0.006
Waste Concentration/WMU Area	0.0006	0.00002	0.006	4.9E-07	0.001	1.7E-08	0.0000002	0.0007	0.00004	0.000002	0.005
Adult Soil Intake/Meteorological Location	0.00001	0.000002	0.0006	3.7E-08	0.0002	2.9E-09	0.00000005	0.00005	0.00002	0.0000006	0.00002
Adult Soil Intake/Distance to Receptor	0.00001	0.000007	0.001	6.3E-08	0.0002	3.5E-09	0.0000001	0.00005	0.00003	0.000001	0.00004
Adult Soil Intake/WMU Area	0.00002	0.000004	0.001	6.1E-08	0.0004	4.7E-09	0.00000009	0.00009	0.00002	0.000001	0.00004
Meteorological Location/Distance to Receptor	0.00001	0.000006	0.001	6.8E-08	0.0002	3.4E-09	0.0000001	0.00007	0.00003	0.000001	0.00004
Meteorological Location/WMU Area	0.00002	0.000003	0.001	7.0E-08	0.0004	4.3E-09	0.00000007	0.0001	0.00002	0.000001	0.00003
Distance to Receptor/WMU Area	0.00001	0.000009	0.001	8.0E-08	0.0002	3.3E-09	0.0000002	0.00005	0.00005	0.000001	0.00005

Table H1-6b Child of Farmer Individual Risk for All Ingestion Pathways for FBC Wastes Managed in Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Central Tendency	0.00051	0.0000028	0.041	4.1E-07	0.0061	3.6E-07	0.000006	0.00073	0.001	0.000031	0.002
Single High-end Parameter											
Long Exposure	0.00051	0.0000028	0.041	5.0E-07	0.0061	4.2E-07	0.000006	0.00073	0.001	0.000031	0.002
Beef intake	0.00052	0.0000028	0.042	4.1E-07	0.0061	3.6E-07	0.000006	0.00073	0.001	0.000031	0.002
Dairy Intake	0.00052	0.0000068	0.041	4.4E-07	0.0061	3.6E-07	0.000006	0.00073	0.001	0.000031	0.002
Exposed Veg. Intake	0.00051	0.0000029	0.041	4.1E-07	0.0062	3.7E-07	0.000006	0.00076	0.001	0.000031	0.002
Root Veg. Intake	0.00051	0.0000028	0.041	4.1E-07	0.0061	3.6E-07	0.000006	0.00073	0.001	0.000031	0.002
Fruit Intake	0.00052	0.000003	0.041	4.1E-07	0.0065	3.7E-07	0.0000062	0.00081	0.001	0.000031	0.002
Waste Concentration	0.02	0.000026	0.21	*3.3E-06*	0.02	*1.8E-06*	0.00001	0.0052	0.002	0.000072	0.3
Adult Soil Intake	0.00051	0.0000028	0.041	4.1E-07	0.0061	3.7E-07	0.000006	0.00073	0.001	0.000031	0.002
Child Soil Intake	0.001	0.0000041	0.091	*1.0E-06*	0.02	9.4E-07	0.00002	0.002	0.003	0.000071	0.005
Meteorological Location	0.00061	0.000003	0.041	5.0E-07	0.0071	4.5E-07	0.000008	0.00093	0.001	0.000031	0.003
Distance to Receptor	0.00081	0.0000083	0.062	7.3E-07	0.0091	6.3E-07	0.00001	0.001	0.0021	0.000052	0.004
WMU Area	0.00072	0.0000052	0.062	6.5E-07	0.01	5.8E-07	0.00001	0.001	0.002	0.000042	0.003
Double High-end Parameters											
Beef Intake/ Long Exposure	0.00052	0.0000028	0.042	5.1E-07	0.0061	4.2E-07	0.000006	0.00073	0.001	0.000031	0.002
Dairy Intake/Long Exposure	0.00052	0.0000068	0.041	5.8E-07	0.0061	4.2E-07	0.000006	0.00073	0.001	0.000031	0.002
Exposed Veg. Intake/ Long Exposure	0.00051	0.0000029	0.041	5.1E-07	0.0062	4.2E-07	0.000006	0.00076	0.001	0.000031	0.002
Root Veg. Intake/Long Exposure	0.00051	0.0000028	0.041	5.0E-07	0.0061	4.2E-07	0.000006	0.00073	0.001	0.000031	0.002
Fruit Intake/ Long Exposure	0.00052	0.000003	0.041	5.2E-07	0.0065	4.3E-07	0.0000062	0.00081	0.001	0.000031	0.002
Waste Concentration/Long Exposure	0.02	0.000026	0.21	*4.1E-06*	0.02	*2.1E-06*	0.00001	0.0052	0.002	0.000072	0.3
Adult Soil Intake/Long Exposure	0.00051	0.0000028	0.041	5.8E-07	0.0061	5.0E-07	0.000006	0.00073	0.001	0.000031	0.002
Child Soil Intake/Long Exposure	0.001	0.0000041	0.091	*1.1E-06*	0.02	9.9E-07	0.00002	0.002	0.003	0.000071	0.005
Meteorological Location/Long Exposure	0.00061	0.000003	0.041	6.2E-07	0.0071	5.2E-07	0.000008	0.00093	0.001	0.000031	0.003
Distance to Receptor/Long Exposure	0.00081	0.0000083	0.062	9.1E-07	0.0091	7.3E-07	0.00001	0.001	0.0021	0.000052	0.004
WMU Area/Long Exposure	0.00072	0.0000052	0.062	8.2E-07	0.01	6.8E-07	0.00001	0.001	0.002	0.000042	0.003
Beef Intake/ Dairy Intake	0.00052	0.0000068	0.043	4.4E-07	0.0061	3.6E-07	0.000006	0.00073	0.001	0.000032	0.002
Beef Intake/ Exposed Veg. Intake	0.00052	0.0000029	0.042	4.1E-07	0.0062	3.7E-07	0.000006	0.00076	0.001	0.000031	0.002
Beef Intake/Root Vegetable Intake	0.00052	0.0000028	0.042	4.1E-07	0.0061	3.7E-07	0.000006	0.00073	0.001	0.000031	0.002
Beef Intake/Fruit Intake	0.00052	0.000003	0.042	4.2E-07	0.0065	3.7E-07	0.0000062	0.00081	0.001	0.000032	0.002
Beef Intake/Waste Concentration	0.021	0.000026	0.21	*3.3E-06*	0.02	*1.8E-06*	0.00001	0.0052	0.0021	0.000074	0.3
Beef Intake/Adult Soil Intake	0.00052	0.0000028	0.042	4.2E-07	0.0061	3.7E-07	0.000006	0.00073	0.001	0.000031	0.002
Beef Intake/Child Soil Intake	0.001	0.0000041	0.092	*1.0E-06*	0.02	9.4E-07	0.00002	0.002	0.003	0.000071	0.005
Beef Intake/Meteorological Location	0.00062	0.000003	0.043	5.0E-07	0.0071	4.5E-07	0.000008	0.00093	0.001	0.000031	0.003
Beef Intake/Distance to Receptor	0.00083	0.0000085	0.064	7.3E-07	0.0091	6.3E-07	0.00001	0.001	0.0021	0.000053	0.0041
Beef Intake/WMU Area	0.00073	0.0000053	0.064	6.5E-07	0.01	5.8E-07	0.00001	0.001	0.0021	0.000043	0.0031
Dairy Intake/Exposed Vegetable Intake	0.00052	0.0000069	0.041	4.4E-07	0.0062	3.7E-07	0.000006	0.00076	0.001	0.000031	0.002
Dairy Intake/Root Vegetable Intake	0.00052	0.0000068	0.041	4.4E-07	0.0062	3.6E-07	0.000006	0.00073	0.001	0.000031	0.002
Dairy Intake/Fruit Intake	0.00052	0.000007	0.042	4.4E-07	0.0065	3.7E-07	0.0000062	0.00081	0.001	0.000031	0.002

Table H1-6b Child of Farmer Individual Risk for All Ingestion Pathways for FBC Wastes Managed in Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Dairy Intake/Waste Concentration	0.021	0.000046	0.21	3.6E-06	0.02	*1.8E-06*	0.00001	0.0052	0.0021	0.000073	0.31
Dairy Intake/ Adult Soil Intake	0.00052	0.0000068	0.041	4.5E-07	0.0061	3.7E-07	0.000006	0.00073	0.001	0.000031	0.002
Dairy Intake/ Child Soil Intake	0.001	0.0000081	0.091	*1.0E-06*	0.02	9.4E-07	0.00002	0.002	0.003	0.000071	0.005
Dairy Intake/ Meteorological Location	0.00062	0.000006	0.042	5.3E-07	0.0072	4.5E-07	0.000008	0.00093	0.001	0.000031	0.003
Dairy Intake/Distance to Receptor	0.00083	0.000021	0.063	7.9E-07	0.0092	6.3E-07	0.00001	0.001	0.0021	0.000052	0.0041
Dairy Intake/WMU Area	0.00073	0.000011	0.063	7.1E-07	0.01	5.8E-07	0.00001	0.001	0.0021	0.000042	0.0031
Exposed Veg. Intake/ Root Veg. Intake	0.00051	0.0000029	0.041	4.1E-07	0.0062	3.7E-07	0.000006	0.00076	0.001	0.000031	0.002
Exposed Veg. Intake/ Fruit Intake	0.00052	0.000003	0.041	4.2E-07	0.0065	3.7E-07	0.0000062	0.00084	0.001	0.000031	0.002
Exposed Veg. Intake/Waste Concentration	0.02	0.000026	0.21	*3.3E-06*	0.021	*1.8E-06*	0.00001	0.0054	0.002	0.000072	0.3
Exposed Veg. Intake/Adult Soil Intake	0.00051	0.0000029	0.041	4.2E-07	0.0062	3.7E-07	0.000006	0.00076	0.001	0.000031	0.002
Exposed Veg. Intake/Child Soil Intake	0.001	0.0000042	0.091	*1.0E-06*	0.02	9.4E-07	0.00002	0.0021	0.003	0.000071	0.005
Exposed Veg. Intake/Meteorological Location	0.00062	0.000003	0.041	5.0E-07	0.0073	4.5E-07	0.000008	0.00097	0.001	0.000031	0.003
Exposed Veg. Intake/Distance to Receptor	0.00082	0.0000084	0.062	7.3E-07	0.0093	6.3E-07	0.00001	0.0011	0.0021	0.000052	0.004
Exposed Veg. Intake/WMU Area	0.00072	0.0000053	0.062	6.6E-07	0.01	5.8E-07	0.00001	0.0011	0.002	0.000042	0.003
Root Veg. Intake/Fruit Intake	0.00052	0.000003	0.041	4.1E-07	0.0065	3.7E-07	0.0000062	0.00081	0.001	0.000031	0.002
Root Veg. Intake/Waste Concentration	0.02	0.000026	0.21	*3.3E-06*	0.02	*1.8E-06*	0.00001	0.0052	0.002	0.000072	0.3
Root Veg. Intake/Adult Soil Intake	0.00051	0.0000028	0.041	4.2E-07	0.0061	3.7E-07	0.000006	0.00073	0.001	0.000031	0.002
Root Veg. Intake/Child Soil Intake	0.001	0.0000041	0.091	*1.0E-06*	0.02	9.4E-07	0.00002	0.002	0.003	0.000071	0.005
Root Veg. Intake/Meteorological Location	0.00061	0.000003	0.041	5.0E-07	0.0071	4.5E-07	0.000008	0.00093	0.001	0.000031	0.003
Root Veg. Intake/Distance to Receptor	0.00081	0.0000083	0.062	7.3E-07	0.0091	6.3E-07	0.00001	0.001	0.0021	0.000052	0.004
Root Veg. Intake/WMU Area	0.00072	0.0000052	0.062	6.5E-07	0.01	5.8E-07	0.00001	0.001	0.002	0.000042	0.003
Fruit Intake/Waste Concentration	0.021	0.000027	0.21	*3.4E-06*	0.022	*1.8E-06*	0.00001	0.006	0.002	0.000073	0.3
Fruit Intake/Adult Soil Intake	0.00052	0.000003	0.041	4.2E-07	0.0065	3.8E-07	0.0000062	0.00081	0.001	0.000031	0.002
Fruit Intake/Child Soil Intake	0.001	0.0000043	0.091	*1.0E-06*	0.02	9.4E-07	0.00002	0.0021	0.003	0.000071	0.005
Fruit Intake/Meteorological Location	0.00062	0.0000032	0.041	5.1E-07	0.0076	4.5E-07	0.0000081	0.001	0.001	0.000031	0.003
Fruit Intake/Distance to Receptor	0.00082	0.0000087	0.063	7.4E-07	0.0096	6.3E-07	0.000011	0.0011	0.0021	0.000052	0.0041
Fruit Intake/WMU Area	0.00073	0.0000055	0.063	6.7E-07	0.011	5.9E-07	0.00001	0.0012	0.002	0.000042	0.0031
Waste Concentration/ Adult Soil Intake	0.02	0.000026	0.21	*3.4E-06*	0.02	*1.9E-06*	0.00001	0.0052	0.002	0.000072	0.3
Waste Concentration/ Child Soil Intake	0.04	0.000031	0.51	***8.2E-06***	0.06	***4.7E-06***	0.00004	0.01	0.004	0.0002	0.7
Waste Concentration/Meteorological Location	0.02	0.000017	0.21	*4.1E-06*	0.02	*2.2E-06*	0.00002	0.0062	0.002	0.000093	0.3
Waste Concentration/Distance to Receptor	0.03	0.000061	0.31	*5.9E-06*	0.03	*3.1E-06*	0.00003	0.0092	0.0031	0.0001	0.51
Waste Concentration/WMU Area	0.031	0.000039	0.31	*5.3E-06*	0.041	*2.9E-06*	0.00002	0.0093	0.0031	0.0001	0.4
Adult Soil Intake/Child Soil Intake	0.001	0.0000041	0.091	*1.0E-06*	0.02	9.4E-07	0.00002	0.002	0.003	0.000071	0.005
Adult Soil Intake/Meteorological Location	0.00061	0.000003	0.041	5.1E-07	0.0071	4.6E-07	0.000008	0.00093	0.001	0.000031	0.003
Adult Soil Intake/Distance to Receptor	0.00081	0.0000083	0.062	7.5E-07	0.0091	6.5E-07	0.00001	0.001	0.0021	0.000052	0.004
Adult Soil Intake/WMU Area	0.00072	0.0000052	0.062	6.7E-07	0.01	6.0E-07	0.00001	0.001	0.002	0.000042	0.003
Child Soil Intake/ Meteorological Location	0.001	0.0000041	0.1	*1.2E-06*	0.02	*1.1E-06*	0.00002	0.002	0.003	0.000091	0.007
Child Soil Intake/Distance to Receptor	0.002	0.000011	0.2	*1.8E-06*	0.02	*1.6E-06*	0.00003	0.003	0.0051	0.0001	0.01
Child Soil Intake/WMU Area	0.002	0.0000072	0.1	*1.6E-06*	0.03	*1.5E-06*	0.00003	0.003	0.004	0.0001	0.009
Meteorological Location/Distance to Receptor	0.001	0.0000083	0.082	8.9E-07	0.01	7.6E-07	0.00001	0.001	0.002	0.000062	0.005

Table H1-6b Child of Farmer Individual Risk for All Ingestion Pathways for FBC Wastes Managed in Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Meteorological Location/WMU Area	0.00092	0.0000052	0.072	8.0E-07	0.01	7.1E-07	0.00001	0.0011	0.002	0.000052	0.004
Distance to Receptor/WMU Area	0.00082	0.000011	0.063	7.5E-07	0.0091	6.3E-07	0.00001	0.001	0.0021	0.000052	0.0041

Table H1-6c Adult Resident Individual Risk from All Ingestion Pathways for FBC Wastes Managed in Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Central Tendency	0.00001	0.00000002	0.0008	4.8E-09	0.0001	4.6E-09	0.0000001	0.00002	0.00002	0.0000006	0.00005
Single High-end Parameter											
Long Exposure	0.00001	0.00000002	0.0008	4.7E-08	0.0001	4.5E-08	0.0000001	0.00002	0.00002	0.0000006	0.00005
Constituent Conc.	0.0004	0.0000001	0.004	3.9E-08	0.0005	2.3E-08	0.0000003	0.0001	0.00004	0.000002	0.006
Adult Soil Intake	0.00002	0.00000004	0.002	1.1E-08	0.0003	1.0E-08	0.0000003	0.00004	0.00005	0.000001	0.0001
Meteorological Location	0.00001	0.00000002	0.001	6.0E-09	0.0002	5.6E-09	0.0000002	0.00002	0.00003	0.0000008	0.00006
Distance To Receptor	0.00002	0.00000003	0.001	8.6E-09	0.0002	7.9E-09	0.0000003	0.00003	0.00004	0.000001	0.00009
WMU Area	0.00002	0.00000003	0.001	7.6E-09	0.0002	7.3E-09	0.0000002	0.00003	0.00004	0.000001	0.00008
Double High-end Parameters											
Constituent Conc./Long Exposure	0.0004	0.0000001	0.004	3.8E-07	0.0005	2.2E-07	0.0000003	0.0001	0.00004	0.000002	0.006
Adult Soil Intake/Long Exposure	0.00002	0.00000004	0.002	1.0E-07	0.0003	9.9E-08	0.0000003	0.00004	0.00005	0.000001	0.0001
Meteorological Location/Long Exposure	0.00001	0.00000002	0.001	5.8E-08	0.0002	5.5E-08	0.0000002	0.00002	0.00003	0.0000008	0.00006
Distance to Receptor/Long Exposure	0.00002	0.00000003	0.001	8.4E-08	0.0002	7.8E-08	0.0000003	0.00003	0.00004	0.000001	0.00009
WMU Area/Long Exposure	0.00002	0.00000003	0.001	7.5E-08	0.0002	7.2E-08	0.0000002	0.00003	0.00004	0.000001	0.00008
Waste Concentration/ Adult Soil Intake	0.0008	0.0000003	0.009	8.6E-08	0.001	5.0E-08	0.0000007	0.0003	0.00008	0.000004	0.01
Waste Concentration/ Meteorological Location	0.0005	0.0000001	0.005	4.8E-08	0.0006	2.8E-08	0.0000004	0.0001	0.00005	0.000002	0.008
Waste Concentration/ Distance to Receptor	0.0006	0.0000002	0.007	7.0E-08	0.0008	3.9E-08	0.0000006	0.0002	0.00007	0.000003	0.01
Waste Concentration/ WMU Area	0.0006	0.0000002	0.006	6.2E-08	0.0008	3.6E-08	0.0000005	0.0002	0.00006	0.000003	0.01
Adult Soil Intake/ Meteorological Location	0.00003	0.00000005	0.002	1.3E-08	0.0003	1.2E-08	0.0000004	0.00005	0.00006	0.000002	0.0001
Adult Soil Intake/ Distance to Receptor	0.00004	0.00000007	0.003	1.9E-08	0.0005	1.7E-08	0.0000006	0.00006	0.00009	0.000002	0.0002
Adult Soil Intake/ WMU Area	0.00004	0.00000006	0.003	1.7E-08	0.0005	1.6E-08	0.0000005	0.00006	0.00008	0.000002	0.0002
Meteorological Location/Distance to Receptor	0.00002	0.00000004	0.002	1.1E-08	0.0002	9.6E-09	0.0000003	0.00003	0.00005	0.000001	0.0001
Meteorological Location/WMU Area	0.00002	0.00000003	0.002	9.5E-09	0.0003	9.0E-09	0.0000003	0.00003	0.00005	0.000001	0.0001
Distance to Receptor/WMU Area	0.00002	0.00000003	0.001	8.6E-09	0.0002	7.9E-09	0.0000003	0.00003	0.00004	0.000001	0.00009

Table H1-6d Home Gardener Individual Risk from All Ingestion Pathways for FBC Wastes Managed in Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Central Tendency	0.00001	0.00000004	0.0008	5.2E-09	0.0001	4.7E-09	0.0000001	0.00003	0.00002	0.0000006	0.00005
Single High-end Parameter											
Long Exposure	0.00001	0.00000004	0.0008	5.0E-08	0.0001	4.6E-08	0.0000001	0.00003	0.00002	0.0000006	0.00005
Exposed Veg. Intake	0.00001	0.00000007	0.0008	5.8E-09	0.0002	4.9E-09	0.0000001	0.00006	0.00002	0.0000007	0.00005
Root Veg.Intake	0.00001	0.00000004	0.0008	5.2E-09	0.0001	4.7E-09	0.0000001	0.00003	0.00002	0.0000006	0.00005
Fruit Intake	0.00001	0.0000001	0.0008	6.1E-09	0.0002	5.0E-09	0.0000002	0.00006	0.00002	0.0000007	0.00005
Constituent Conc.	0.0004	0.0000002	0.004	4.2E-08	0.0006	2.3E-08	0.0000003	0.0002	0.00004	0.000002	0.006
Adult Soil Intake	0.00002	0.00000006	0.002	1.1E-08	0.0003	1.0E-08	0.0000003	0.00005	0.00005	0.000001	0.0001
Meteorological Location	0.00001	0.00000004	0.001	6.4E-09	0.0003	5.7E-09	0.0000002	0.00003	0.00003	0.0000008	0.00006
Distance To Receptor	0.00002	0.00000007	0.001	9.1E-09	0.0003	8.1E-09	0.0000003	0.00004	0.00004	0.000001	0.00009
WMU Area	0.00002	0.00000006	0.001	8.3E-09	0.0003	7.5E-09	0.0000002	0.00005	0.00004	0.000001	0.00008
Double High-end Parameters											
Exposed Veg. Intake/Long Exposure	0.00001	0.00000007	0.0008	5.7E-08	0.0002	4.8E-08	0.0000001	0.00006	0.00002	0.0000007	0.00005
Root Veg. Intake/Long Exposure	0.00001	0.00000004	0.0008	5.1E-08	0.0001	4.6E-08	0.0000001	0.00003	0.00002	0.0000006	0.00005
Fruit Intake/Long Exposure	0.00001	0.0000001	0.0008	6.0E-08	0.0002	4.9E-08	0.0000002	0.00006	0.00002	0.0000007	0.00005
Constituent Conc./Long Exposure	0.0004	0.0000002	0.004	4.1E-07	0.0006	2.3E-07	0.0000003	0.0002	0.00004	0.000002	0.006
Adult Soil Intake/Long Exposure	0.00002	0.00000006	0.002	1.1E-07	0.0003	1.0E-07	0.0000003	0.00005	0.00005	0.000001	0.0001
Meteorological Location/Long Exposure	0.00001	0.00000004	0.001	6.2E-08	0.0003	5.6E-08	0.0000002	0.00003	0.00003	0.0000008	0.00006
Distance to Receptor/Long Exposure	0.00002	0.00000007	0.001	8.9E-08	0.0003	7.9E-08	0.0000003	0.00004	0.00004	0.000001	0.00009
WMU Area/Long Exposure	0.00002	0.00000006	0.001	8.1E-08	0.0003	7.4E-08	0.0000002	0.00005	0.00004	0.000001	0.00008
Exposed Veg. Intake/Root Veg. Intake	0.00001	0.00000007	0.0008	5.8E-09	0.0002	4.9E-09	0.0000001	0.00006	0.00002	0.0000007	0.00005
Exposed Veg. Intake/ Fruit Intake	0.00001	0.0000001	0.0009	6.8E-09	0.0003	5.1E-09	0.0000002	0.00009	0.00002	0.0000008	0.00005
Exposed Veg. Intake/Waste Concentration	0.0005	0.0000005	0.004	4.7E-08	0.0009	2.4E-08	0.0000004	0.0004	0.00004	0.000002	0.006
Exposed Veg. Intake/Adult Soil Intake	0.00002	0.00000009	0.002	1.2E-08	0.0004	1.0E-08	0.0000003	0.00008	0.00005	0.000001	0.0001
Exposed Veg. Intake/Meteorological Location	0.00001	0.00000007	0.001	7.2E-09	0.0003	5.9E-09	0.0000002	0.00006	0.00003	0.0000009	0.00006
Exposed Veg. Intake/ Distance to Receptor	0.00002	0.0000001	0.001	1.0E-08	0.0003	8.4E-09	0.0000004	0.00007	0.00004	0.000001	0.00009
Exposed Veg. Intake/WMU Area	0.00002	0.0000001	0.001	9.5E-09	0.0005	7.9E-09	0.0000002	0.00009	0.00004	0.000001	0.00008
Root Veg. Intake/Fruit Intake	0.00001	0.0000001	0.0008	6.2E-09	0.0002	5.0E-09	0.0000002	0.00007	0.00002	0.0000007	0.00005
Root Veg. Intake/Waste Concentration	0.0004	0.0000002	0.004	4.2E-08	0.0007	2.3E-08	0.0000003	0.0002	0.00004	0.000002	0.006
Root Veg. Intake/Adult Soil Intake	0.00002	0.00000006	0.002	1.1E-08	0.0003	1.0E-08	0.0000003	0.00005	0.00005	0.000001	0.0001
Root Veg. Intake/ Meteorological Location	0.00001	0.00000004	0.001	6.5E-09	0.0003	5.7E-09	0.0000002	0.00004	0.00003	0.0000008	0.00006
Root Veg. Intake/ Distance to Receptor	0.00002	0.00000007	0.001	9.2E-09	0.0003	8.1E-09	0.0000003	0.00005	0.00004	0.000001	0.00009
Root Intake/WMU Area	0.00002	0.00000007	0.001	8.4E-09	0.0003	7.5E-09	0.0000002	0.00005	0.00004	0.000001	0.00008
Fruit Intake/Waste Concentration	0.0005	0.0000006	0.004	5.0E-08	0.001	2.5E-08	0.0000004	0.0004	0.00004	0.000002	0.006
Fruit Intake/Adult Soil Intake	0.00002	0.0000001	0.002	1.2E-08	0.0004	1.0E-08	0.0000004	0.00008	0.00005	0.000001	0.0001
Fruit Intake/ Meteorological Location	0.00001	0.0000001	0.001	7.6E-09	0.0004	6.1E-09	0.0000002	0.00008	0.00003	0.0000009	0.00006
Fruit Intake/ Distance to Receptor	0.00002	0.0000002	0.001	1.1E-08	0.0004	8.6E-09	0.0000005	0.00009	0.00005	0.000001	0.0001
Fruit Intake/ WMU Area	0.00002	0.0000001	0.001	1.0E-08	0.0005	8.1E-09	0.0000003	0.0001	0.00004	0.000001	0.00009
Waste Concentration/ Adult Soil Intake	0.0008	0.0000004	0.009	8.9E-08	0.001	5.1E-08	0.0000007	0.0004	0.00008	0.000004	0.01
Waste Concentration/ Meteorological Location	0.0005	0.0000002	0.005	5.2E-08	0.0008	2.8E-08	0.0000004	0.0002	0.00005	0.000002	0.008
Waste Concentration/ Distance to Receptor	0.0006	0.0000005	0.007	7.4E-08	0.001	4.0E-08	0.0000007	0.0003	0.00007	0.000003	0.01

Table H1-6d Home Gardener Individual Risk from All Ingestion Pathways for FBC Wastes Managed in Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Waste Concentration/ WMU Area	0.0007	0.0000005	0.006	6.8E-08	0.001	3.7E-08	0.0000005	0.0004	0.00006	0.000003	0.01
Adult Soil Intake/ Meteorological Location	0.00003	0.00000007	0.002	1.4E-08	0.0004	1.2E-08	0.0000004	0.00006	0.00006	0.000002	0.0001
Adult Soil Intake/ Distance to Receptor	0.00004	0.0000001	0.003	1.9E-08	0.0006	1.8E-08	0.0000006	0.00007	0.00009	0.000002	0.0002
Adult Soil Intake/ WMU Area	0.00004	0.00000009	0.003	1.7E-08	0.0006	1.6E-08	0.0000005	0.00008	0.00008	0.000002	0.0002
Meteorological Location/Distance to Receptor	0.00002	0.00000008	0.002	1.1E-08	0.0003	9.8E-09	0.0000003	0.00005	0.00005	0.000001	0.0001
Meteorological Location/WMU Area	0.00002	0.00000007	0.002	1.0E-08	0.0004	9.2E-09	0.0000003	0.00006	0.00005	0.000001	0.0001
Distance to Receptor/WMU Area	0.00002	0.00000008	0.001	9.2E-09	0.0003	8.1E-09	0.0000004	0.00004	0.00004	0.000001	0.00009

Table H1-6e Fisher Individual Risk from All Ingestion Pathways for FBC Wastes Managed in Onsite Landfill

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Central Tendency	0.0000003	0.000004	0.00003	6.6E-10	0.0000003	1.5E-10	0.000001	0.0000004	0.000008	0.00000004	0.000003
Single High-end Parameter											
Long Exposure	0.0000003	0.000004	0.00003	6.4E-09	0.0000003	1.5E-09	0.000001	0.0000004	0.000008	0.00000004	0.000003
Fish Intake	0.0000003	0.000004	0.00008	7.3E-10	0.0000003	2.4E-10	0.000001	0.000001	0.000008	0.00000004	0.000003
Waste Concentration	0.000009	0.00003	0.0001	5.3E-09	0.000001	7.6E-10	0.000003	0.000002	0.00001	0.0000001	0.0003
Meteorological Location	0.00000004	0.0000002	0.000004	5.8E-11	0.0000001	2.1E-11	0.00000007	0.00000007	0.0000006	0.000000004	0.0000003
Distance to Receptor	0.0000003	0.000004	0.00004	6.8E-10	0.0000004	1.7E-10	0.000001	0.0000004	0.000008	0.00000004	0.000003
WMU Area	0.0000005	0.000009	0.00007	1.3E-09	0.0000007	3.1E-10	0.000003	0.0000006	0.00002	0.00000008	0.000005
Double High-end Parameters											
Fish Intake/Long Exposure	0.0000003	0.000004	0.00008	7.1E-09	0.0000003	2.3E-09	0.000001	0.000001	0.000008	0.00000004	0.000003
Waste Concentration/Long Exposure	0.000009	0.00003	0.0001	5.2E-08	0.000001	7.5E-09	0.000003	0.000002	0.00001	0.0000001	0.0003
Meteorological Location/Long Exposure	0.00000004	0.0000002	0.000004	5.7E-10	0.0000001	2.0E-10	0.00000007	0.00000007	0.0000006	0.000000004	0.0000003
Distance to Receptor/Long Exposure	0.0000003	0.000004	0.00004	6.7E-09	0.0000004	1.6E-09	0.000001	0.0000004	0.000008	0.00000004	0.000003
WMU Area/Long Exposure	0.0000005	0.000009	0.00007	1.3E-08	0.0000007	3.0E-09	0.000003	0.0000006	0.00002	0.00000008	0.000005
Fish Intake/Waste Concentration	0.000009	0.00003	0.0004	5.9E-09	0.000001	1.2E-09	0.000003	0.000009	0.00001	0.0000001	0.0003
Fish Intake/Meteorological Location	0.00000004	0.0000002	0.00001	6.4E-11	0.0000001	3.2E-11	0.00000007	0.0000002	0.0000006	0.000000004	0.0000003
Fish Intake/Distance to Receptor	0.0000003	0.000004	0.00009	7.6E-10	0.0000004	2.5E-10	0.000001	0.000001	0.000008	0.00000004	0.000003
Fish Intake/WMU Area	0.0000005	0.000009	0.0002	1.5E-09	0.0000007	4.7E-10	0.000003	0.000002	0.00002	0.00000008	0.000005
Waste Concentration/Meteorological Location	0.000001	0.000001	0.00003	4.7E-10	0.0000005	1.0E-10	0.0000002	0.0000005	0.0000009	0.00000001	0.00004
Waste Concentration/Distance to Receptor	0.00001	0.00003	0.0002	5.6E-09	0.000001	8.2E-10	0.000003	0.000002	0.00001	0.0000001	0.0004
Waste Concentration/WMU Area	0.00002	0.00006	0.0003	1.1E-08	0.000002	1.5E-09	0.000006	0.000004	0.00002	0.0000002	0.0007
Meteorological Location/Distance to Receptor	0.00000006	0.0000002	0.000007	8.0E-11	0.0000002	3.1E-11	0.00000007	0.0000001	0.0000007	0.000000006	0.0000004
Meteorological Location/WMU Area	0.00000007	0.0000004	0.000008	1.1E-10	0.0000002	4.1E-11	0.0000001	0.0000001	0.000001	0.000000008	0.0000006
Distance to Receptor/WMU Area	0.0000003	0.000004	0.00004	7.0E-10	0.0000004	1.7E-10	0.000001	0.0000004	0.000008	0.00000004	0.000003

Table H1-7a Farmer Individual Risk from All Ingestion Pathways for FBC Wastes Applied as Agricultural Soil Amendment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Central Tendency	0.0000002	0.00000004	0.00001	7.45E-10	0.000004	5.0E-11	0.0000000002	0.000001	0.0000002	0.00000001	0.0000004
Single High-end Parameter											
Long Exposure	0.0000002	0.00000003	0.00001	4.27E-09	0.000004	2.8E-10	0.0000000002	0.000001	0.0000002	0.00000001	0.0000004
Beef intake	0.0000008	0.00000005	0.0001	9.16E-10	0.000004	9.2E-11	0.0000000002	0.000001	0.0000006	0.00000006	0.0000007
Dairy Intake	0.0000005	0.0000001	0.00002	2.33E-09	0.000005	5.0E-11	0.0000000002	0.000001	0.0000004	0.00000003	0.000001
Exposed Veg. Intake	0.0000003	0.00000005	0.00001	8.75E-10	0.000007	8.4E-11	0.0000000002	0.000003	0.0000002	0.00000001	0.0000004
Root Veg. Intake	0.0000002	0.00000005	0.00001	7.59E-10	0.000004	5.2E-11	0.0000000002	0.000001	0.0000002	0.00000001	0.0000004
Fruit Intake	0.0000004	0.00000005	0.00001	1.03E-09	0.00001	1.3E-10	0.0000000002	0.000004	0.0000003	0.00000002	0.0000005
Application Rate	0.0000004	0.00000007	0.00002	1.22E-09	0.000005	7.9E-11	0.0000000003	0.000002	0.0000003	0.00000002	0.0000006
Application Frequency	0.0000004	0.00000007	0.00002	1.23E-09	0.000007	8.2E-11	0.0000000003	0.000002	0.0000003	0.00000002	0.0000006
Constituent Concentration	0.000008	0.0000002	0.00006	6.06E-09	0.00001	2.5E-10	0.0000000005	0.000009	0.0000003	0.00000003	0.00005
Tilling Depth	0.0000002	0.00000006	0.00001	7.52E-10	0.000005	5.0E-11	0.0000000002	0.000001	0.0000002	0.00000001	0.0000004
Adult Soil Ingestion	0.0000002	0.00000004	0.00001	7.66E-10	0.000004	7.0E-11	0.0000000004	0.000001	0.0000002	0.00000001	0.0000004
Double High-end Parameters											
Beef Intake/Long Exposure	0.0000008	0.00000004	0.0001	5.25E-09	0.000004	5.2E-10	0.0000000002	0.000001	0.0000006	0.00000006	0.0000007
Dairy Intake/Long Exposure	0.0000005	0.0000001	0.00002	1.34E-08	0.000005	2.8E-10	0.0000000002	0.000001	0.0000004	0.00000003	0.000001
Exposed Veg. Intake/ Long Exposure	0.0000003	0.00000004	0.00001	5.02E-09	0.000007	4.8E-10	0.0000000002	0.000003	0.0000002	0.00000001	0.0000004
Root Veg. Intake/Long Exposure	0.0000002	0.00000003	0.00001	4.35E-09	0.000004	3.0E-10	0.0000000002	0.000001	0.0000002	0.00000001	0.0000004
Fruit Intake/ Long Exposure	0.0000004	0.00000004	0.00001	5.92E-09	0.00001	7.2E-10	0.0000000002	0.000004	0.0000003	0.00000002	0.0000005
Application Rate/Long Exposure	0.0000004	0.00000006	0.00002	6.99E-09	0.000005	4.5E-10	0.0000000003	0.000002	0.0000003	0.00000002	0.0000006
Application Frequency/Long Exposure	0.0000004	0.00000006	0.00002	7.12E-09	0.000005	4.7E-10	0.0000000003	0.000002	0.0000003	0.00000002	0.0000006
Constituent Concentration/Long Exposure	0.000008	0.0000002	0.00006	3.48E-08	0.00001	1.4E-09	0.0000000004	0.000008	0.0000003	0.00000003	0.00005
Tilling Depth/Long Exposure	0.0000002	0.00000006	0.00001	4.28E-09	0.000004	2.9E-10	0.0000000002	0.000001	0.0000002	0.00000001	0.0000004
Soil Ingestion/Long Exposure	0.0000002	0.00000003	0.00001	4.39E-09	0.000004	4.0E-10	0.0000000004	0.000001	0.0000002	0.00000001	0.0000004
Beef Intake/Dairy Intake	0.000001	0.0000001	0.0001	2.5E-09	0.000005	9.2E-11	0.0000000002	0.000001	0.0000008	0.00000007	0.000001
Beef Intake/Exposed Veg. Intake	0.0000009	0.00000005	0.0001	1.05E-09	0.000007	1.3E-10	0.0000000002	0.000003	0.0000006	0.00000006	0.0000008
Beef Intake/Root Vegetable Intake	0.0000008	0.00000005	0.0001	9.29E-10	0.000004	9.4E-11	0.0000000002	0.000001	0.0000006	0.00000006	0.0000007
Beef Intake/Fruit Intake	0.0000009	0.00000006	0.0001	1.2E-09	0.00001	1.7E-10	0.0000000002	0.000004	0.0000006	0.00000007	0.0000009
Beef Intake/Application Rate	0.000001	0.00000007	0.0002	1.5E-09	0.000005	1.5E-10	0.0000000003	0.000002	0.0000009	0.00000009	0.000001
Beef Intake/Application Frequency	0.000001	0.00000007	0.0002	1.51E-09	0.000007	1.5E-10	0.0000000003	0.000002	0.0000009	0.00000009	0.000001
Beef Intake/Constituent Concentration	0.00003	0.0000003	0.0005	7.45E-09	0.00001	4.6E-10	0.0000000005	0.000009	0.0000009	0.0000001	0.0001
Beef Intake/Small Tilling Depth	0.0000008	0.00000006	0.0001	9.25E-10	0.000005	9.3E-11	0.0000000002	0.000001	0.0000006	0.00000006	0.0000007
Beef Intake/Adult Soil Ingestion	0.0000008	0.00000005	0.0001	9.37E-10	0.000004	1.1E-10	0.0000000004	0.000001	0.0000006	0.00000006	0.0000008
Dairy Intake/Exposed Vegetable Intake	0.0000006	0.0000001	0.00002	2.46E-09	0.000008	8.4E-11	0.0000000002	0.000003	0.0000005	0.00000003	0.000001
Dairy Intake/Root Vegetable Intake	0.0000005	0.0000001	0.00002	2.34E-09	0.000005	5.2E-11	0.0000000002	0.000001	0.0000004	0.00000003	0.000001
Dairy Intake/Fruit Intake	0.0000007	0.0000001	0.00002	2.62E-09	0.00001	1.3E-10	0.0000000002	0.000004	0.0000005	0.00000003	0.000001
Dairy Intake/Application Rate	0.0000009	0.0000002	0.00003	3.81E-09	0.000007	7.9E-11	0.0000000003	0.000002	0.0000007	0.00000004	0.000001
Dairy Intake/Application Frequency	0.0000009	0.0000002	0.00003	3.84E-09	0.000009	8.2E-11	0.0000000003	0.000002	0.0000007	0.00000004	0.000001
Dairy Intake/Constituent Concentration	0.00001	0.0000009	0.0001	1.9E-08	0.00002	2.5E-10	0.0000000005	0.000009	0.0000007	0.00000007	0.0001
Dairy Intake/Tilling Depth	0.0000005	0.0000002	0.00002	2.35E-09	0.000006	5.0E-11	0.0000000002	0.000001	0.0000004	0.00000003	0.000001
Dairy Intake/Adult Soil Ingestion	0.0000005	0.0000001	0.00002	2.35E-09	0.000005	7.0E-11	0.0000000004	0.000001	0.0000004	0.00000003	0.000001
Exposed Veg. Intake/Root Veg. Intake	0.0000003	0.00000005	0.00001	8.89E-10	0.000007	8.6E-11	0.0000000002	0.000003	0.0000003	0.00000001	0.0000004

Table H1-7a Farmer Individual Risk from All Ingestion Pathways for FBC Wastes Applied as Agricultural Soil Amendment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Exposed Veg. Intake/Fruit Intake	0.0000005	0.00000006	0.00002	1.16E-09	0.00001	1.6E-10	0.0000000002	0.000006	0.0000003	0.00000002	0.0000006
Exposed Veg. Intake/Application Rate	0.0000006	0.00000008	0.00002	1.43E-09	0.00001	1.3E-10	0.0000000003	0.000004	0.0000003	0.00000002	0.0000007
Exposed Veg. Intake/Application Frequency	0.0000006	0.00000008	0.00002	1.44E-09	0.00001	1.4E-10	0.0000000003	0.000004	0.0000003	0.00000003	0.0000007
Exposed Veg. Intake/Constituent Concentration	0.00001	0.0000003	0.00006	7.12E-09	0.00003	4.2E-10	0.0000000005	0.00002	0.0000003	0.00000004	0.00006
Exposed Veg. Intake/Tilling Depth	0.0000003	0.00000006	0.00001	8.84E-10	0.00001	8.5E-11	0.0000000002	0.000003	0.0000002	0.00000001	0.0000004
Exposed Veg. Intake/Adult Soil Ingestion	0.0000003	0.00000005	0.00001	8.96E-10	0.000007	1.0E-10	0.0000000004	0.000003	0.0000003	0.00000002	0.0000005
Root Veg. Intake/Fruit Intake	0.0000004	0.00000005	0.00001	1.05E-09	0.00001	1.3E-10	0.0000000002	0.000005	0.0000003	0.00000002	0.0000005
Root Veg. Intake/Application Rate	0.0000004	0.00000007	0.00002	1.24E-09	0.000005	8.3E-11	0.0000000003	0.000002	0.0000003	0.00000002	0.0000007
Root Veg. Intake/Application Frequency	0.0000004	0.00000007	0.00002	1.25E-09	0.000007	8.6E-11	0.0000000003	0.000002	0.0000003	0.00000002	0.0000007
Root Veg. Intake/Constituent Concentration	0.000009	0.0000002	0.00006	6.17E-09	0.00001	2.6E-10	0.0000000005	0.00001	0.0000003	0.00000003	0.00005
Root Veg. Intake/Tilling Depth	0.0000002	0.00000006	0.00001	7.66E-10	0.000005	5.3E-11	0.0000000002	0.000002	0.0000002	0.00000001	0.0000004
Root Veg. Intake/Adult Soil Ingestion	0.0000003	0.00000005	0.00001	7.8E-10	0.000004	7.2E-11	0.0000000004	0.000001	0.0000002	0.00000001	0.0000004
Fruit Intake/Application Rate	0.0000007	0.00000008	0.00002	1.69E-09	0.00002	2.0E-10	0.0000000003	0.000007	0.0000004	0.00000002	0.0000009
Fruit Intake/Application Frequency	0.0000007	0.00000008	0.00002	1.7E-09	0.00002	2.1E-10	0.0000000003	0.000008	0.0000004	0.00000003	0.0000009
Fruit Intake/Constituent Concentration	0.00001	0.0000003	0.00007	8.4E-09	0.00005	6.3E-10	0.0000000005	0.00003	0.0000004	0.00000004	0.00007
Fruit Intake/Tilling Depth	0.0000004	0.00000007	0.00001	1.04E-09	0.00001	1.3E-10	0.0000000002	0.000004	0.0000003	0.00000002	0.0000005
Fruit Intake/Adult Soil Ingestion	0.0000004	0.00000005	0.00002	1.05E-09	0.00001	1.5E-10	0.0000000004	0.000004	0.0000003	0.00000002	0.0000006
Appplication Rate/Application Frequency	0.0000006	0.0000001	0.00003	2.01E-09	0.000008	1.3E-10	0.0000000005	0.000003	0.0000005	0.00000003	0.000001
Appplication Rate/Constituent Concentration	0.00001	0.0000004	0.00009	9.92E-09	0.00002	3.9E-10	0.0000000008	0.00001	0.0000005	0.00000005	0.00008
Appplication Rate/Tilling Depth	0.0000004	0.0000001	0.00002	1.23E-09	0.000007	8.0E-11	0.0000000004	0.000002	0.0000003	0.00000002	0.0000006
Appplication Rate/Adult Soil Ingestion	0.0000004	0.00000007	0.00002	1.25E-09	0.000005	1.1E-10	0.0000000007	0.000002	0.0000003	0.00000002	0.0000007
Appplication Frequency/Constituent Concentration	0.00001	0.0000004	0.00009	9.98E-09	0.00002	4.1E-10	0.0000000007	0.00001	0.0000005	0.00000006	0.00008
Appplication Frequency/Tilling Depth	0.0000004	0.0000001	0.00002	1.23E-09	0.000007	8.3E-11	0.0000000003	0.000003	0.0000003	0.00000002	0.0000006
Appplication Frequency/Adult Soil Ingestion	0.0000005	0.00000007	0.00002	1.26E-09	0.000007	1.2E-10	0.0000000007	0.000002	0.0000003	0.00000002	0.0000007
Constituent Concentration/Tilling Depth	0.000008	0.0000004	0.00006	6.12E-09	0.00002	2.5E-10	0.0000000005	0.00001	0.0000003	0.00000003	0.00005
Constituent Concentration/Adult Soil Ingestion	0.000009	0.0000002	0.00006	6.23E-09	0.00001	3.5E-10	0.0000000010	0.00001	0.0000003	0.00000003	0.00006
Adult Soil Ingestion/Tilling Depth	0.0000002	0.00000006	0.00001	7.74E-10	0.000005	7.1E-11	0.0000000005	0.000001	0.0000002	0.00000001	0.0000004

Table H1-7b Child of Farmer Individual Risk from All Ingestion Pathways for FBC Wastes Applied as Agricultural Soil Amendment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Central Tendency	0.0000008	0.00000005	0.00006	1.0E-09	0.000007	4.5E-10	0.000000008	0.000002	0.000001	0.00000005	0.000003
Single High-end Parameter											
Long Exposure	0.0000007	0.00000004	0.00006	1.9E-09	0.000007	5.4E-10	0.000000008	0.000001	0.000001	0.00000005	0.000002
Beef intake	0.000001	0.00000005	0.00009	1.1E-09	0.000007	4.6E-10	0.000000008	0.000002	0.000001	0.00000007	0.000004
Dairy Intake	0.000001	0.0000001	0.00007	1.7E-09	0.000008	4.5E-10	0.000000008	0.000002	0.000001	0.00000005	0.000004
Exposed Veg. Intake	0.0000009	0.00000005	0.00007	1.1E-09	0.00001	4.7E-10	0.000000008	0.000002	0.000001	0.00000005	0.000004
Root Veg. Intake	0.0000009	0.00000005	0.00006	1.0E-09	0.000007	4.6E-10	0.000000008	0.000002	0.000001	0.00000005	0.000003
Fruit Intake	0.000001	0.00000005	0.00007	1.2E-09	0.00002	5.1E-10	0.000000008	0.000005	0.000001	0.00000005	0.000004
Application Rate	0.000001	0.00000008	0.0001	1.7E-09	0.00001	7.3E-10	0.00000001	0.000002	0.000002	0.00000008	0.000005
Application Frequency	0.000001	0.00000008	0.0001	1.7E-09	0.00001	7.5E-10	0.00000001	0.000002	0.000002	0.00000008	0.000005
Constituent Concentration	0.00003	0.0000003	0.0003	8.4E-09	0.00003	2.3E-09	0.00000002	0.00001	0.000002	0.0000001	0.0003
Small Tilling Depth	0.000001	0.00000007	0.00006	1.0E-09	0.000008	4.6E-10	0.000000009	0.000002	0.000001	0.00000005	0.000003
Adult Soil intake	0.0000008	0.00000005	0.00006	1.0E-09	0.000007	4.6E-10	0.000000008	0.000002	0.000001	0.00000005	0.000003
Child Soil intake	0.000001	0.00000005	0.0001	1.8E-09	0.00001	1.1E-09	0.00000002	0.000003	0.000003	0.00000010	0.000007
Double High-end Parameters											
Beef Intake/ Long Exposure	0.0000009	0.00000005	0.00009	2.0E-09	0.000007	5.7E-10	0.000000008	0.000001	0.000001	0.00000007	0.000003
Dairy Intake/Long Exposure	0.0000009	0.00000009	0.00007	3.6E-09	0.000008	5.4E-10	0.000000008	0.000001	0.000001	0.00000005	0.000003
Exposed Veg. Intake/ Long Exposure	0.0000008	0.00000005	0.00007	2.1E-09	0.00001	5.8E-10	0.000000008	0.000002	0.000001	0.00000005	0.000003
Root Veg. Intake/Long Exposure	0.0000008	0.00000005	0.00006	1.9E-09	0.000007	5.4E-10	0.000000008	0.000002	0.000001	0.00000005	0.000002
Fruit Intake/ Long Exposure	0.0000009	0.00000005	0.00007	2.4E-09	0.00002	6.8E-10	0.000000008	0.000004	0.000001	0.00000005	0.000003
Application Rate/Long Exposure	0.000001	0.00000007	0.0001	3.1E-09	0.00001	8.6E-10	0.00000001	0.000002	0.000002	0.00000008	0.000005
Application Frequency/Long Exposure	0.000001	0.00000007	0.0001	3.2E-09	0.00001	9.0E-10	0.00000001	0.000002	0.000002	0.00000008	0.000005
Constituent Concentration/Long Exposure	0.00003	0.0000002	0.0003	1.6E-08	0.00003	2.7E-09	0.00000002	0.00001	0.000002	0.0000001	0.0003
Small Tilling Depth/Long Exposure	0.0000008	0.00000007	0.00006	1.9E-09	0.000008	5.5E-10	0.000000008	0.000002	0.000001	0.00000005	0.000003
Adult Soil intake/Long Exposure	0.0000007	0.00000004	0.00006	2.0E-09	0.000007	6.3E-10	0.000000008	0.000001	0.000001	0.00000005	0.000002
Child Soil intake/Long Exposure	0.000001	0.00000005	0.0001	2.6E-09	0.00001	1.2E-09	0.00000002	0.000003	0.000003	0.00000010	0.000006
Beef Intake/ Dairy Intake	0.000001	0.0000001	0.0001	1.8E-09	0.000008	4.6E-10	0.000000008	0.000002	0.000001	0.00000007	0.000004
Beef Intake/ Exposed Veg. Intake	0.000001	0.00000005	0.0001	1.1E-09	0.00001	4.8E-10	0.000000008	0.000002	0.000001	0.00000007	0.000004
Beef Intake/Root Vegetable Intake	0.000001	0.00000005	0.00009	1.1E-09	0.000007	4.7E-10	0.000000008	0.000002	0.000001	0.00000007	0.000004
Beef Intake/Fruit Intake	0.000001	0.00000006	0.0001	1.3E-09	0.00002	5.2E-10	0.000000008	0.000005	0.000001	0.00000007	0.000004
Beef Intake/ Application Rate	0.000002	0.00000008	0.0002	1.8E-09	0.00001	7.4E-10	0.00000001	0.000002	0.000003	0.0000001	0.000005
Beef Intake/Application Frequency	0.000002	0.00000008	0.0002	1.8E-09	0.00001	7.7E-10	0.00000001	0.000002	0.000003	0.0000001	0.000005
Beef Intake/Constituent Concentration	0.00004	0.0000003	0.0005	8.8E-09	0.00003	2.3E-09	0.00000002	0.00001	0.000003	0.0000002	0.0004
Beef Intake/Small Tilling Depth	0.000001	0.00000007	0.0001	1.1E-09	0.000008	4.7E-10	0.000000009	0.000002	0.000001	0.00000007	0.000004
Beef Intake/Adult Soil Ingestion	0.000001	0.00000005	0.00009	1.1E-09	0.000007	4.7E-10	0.000000008	0.000002	0.000001	0.00000007	0.000004
Beef Intake/Child Soil Ingestion	0.000001	0.00000005	0.0002	1.8E-09	0.00001	1.1E-09	0.00000002	0.000003	0.000003	0.0000001	0.000008
Dairy Intake/Exposed Vegetable Intake	0.000001	0.0000001	0.00007	1.8E-09	0.00001	4.7E-10	0.000000008	0.000002	0.000001	0.00000005	0.000004
Dairy Intake/Root Vegetable Intake	0.000001	0.0000001	0.00007	1.7E-09	0.000008	4.6E-10	0.000000008	0.000002	0.000001	0.00000005	0.000004
Dairy Intake/Fruit Intake	0.000001	0.0000001	0.00007	1.9E-09	0.00002	5.1E-10	0.000000008	0.000005	0.000001	0.00000006	0.000004
Dairy Intake/ Application Rate	0.000002	0.0000002	0.0001	2.8E-09	0.00001	7.3E-10	0.00000001	0.000002	0.000003	0.00000009	0.000005
Dairy Intake/ Application Frequency	0.000002	0.0000002	0.0001	2.9E-09	0.00001	7.5E-10	0.00000001	0.000002	0.000003	0.00000009	0.000005
Dairy Intake/ Constituent Concentration	0.00004	0.0000007	0.0004	1.4E-08	0.00003	2.3E-09	0.00000002	0.00001	0.000003	0.0000002	0.0004
Dairy Intake/ Tilling Depth	0.000001	0.0000001	0.00007	1.8E-09	0.00001	4.6E-10	0.000000009	0.000002	0.000001	0.00000005	0.000004

Table H1-7b Child of Farmer Individual Risk from All Ingestion Pathways for FBC Wastes Applied as Agricultural Soil Amendment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Dairy Intake/Adult Soil Ingestion	0.000001	0.0000001	0.00007	1.7E-09	0.00001	4.6E-10	0.000000008	0.000002	0.000001	0.00000005	0.000004
Dairy Intake/Child Soil Ingestion	0.000001	0.0000001	0.0001	2.5E-09	0.00001	1.1E-09	0.00000002	0.000003	0.000003	0.0000001	0.000008
Exposed Veg. Intake/ Root Veg. Intake	0.000001	0.00000005	0.00007	1.1E-09	0.00001	4.7E-10	0.000000008	0.000002	0.000001	0.00000005	0.000004
Exposed Veg. Intake/ Fruit Intake	0.000001	0.00000006	0.00007	1.3E-09	0.00002	5.3E-10	0.000000008	0.000006	0.000001	0.00000006	0.000004
Exposed Veg. Intake/ Application Rate	0.000001	0.00000009	0.0001	1.8E-09	0.00002	7.5E-10	0.00000001	0.000004	0.000003	0.00000008	0.000005
Exposed Veg. Intake/Application Frequency	0.000002	0.00000009	0.0001	1.8E-09	0.00002	7.8E-10	0.00000001	0.000004	0.000003	0.00000009	0.000005
Exposed Veg. Intake/Constituent Concentration	0.00003	0.0000004	0.0003	8.9E-09	0.00004	2.3E-09	0.00000002	0.00002	0.000003	0.0000001	0.0004
Exposed Veg. Intake/Tilling Depth	0.0000009	0.00000007	0.00007	1.1E-09	0.00001	4.8E-10	0.000000009	0.000002	0.000001	0.00000005	0.000004
Exposed Veg. Intake/Adult Soil Ingestion	0.0000009	0.00000005	0.00007	1.1E-09	0.00001	4.8E-10	0.000000008	0.000002	0.000001	0.00000005	0.000004
Exposed Veg. Intake/Child Soil Ingestion	0.000001	0.00000005	0.0001	1.8E-09	0.00002	1.2E-09	0.00000002	0.000004	0.000003	0.00000010	0.000008
Root Veg. Intake/Fruit Intake	0.000001	0.00000005	0.00007	1.3E-09	0.00002	5.1E-10	0.000000008	0.000005	0.000001	0.00000005	0.000004
Root Veg. Intake/ Application Rate	0.000001	0.00000008	0.0001	1.7E-09	0.00001	7.3E-10	0.00000001	0.000002	0.000003	0.00000008	0.000005
Root Veg. Intake/Application Frequency	0.000001	0.00000008	0.0001	1.7E-09	0.00001	7.6E-10	0.00000001	0.000002	0.000003	0.00000008	0.000005
Root Veg. Intake/Constituent Concentration	0.00003	0.0000003	0.0003	8.5E-09	0.00003	2.3E-09	0.00000002	0.00001	0.000003	0.0000001	0.0004
Root Veg. Intake/Tilling Depth	0.0000009	0.00000007	0.00006	1.1E-09	0.000009	4.6E-10	0.000000009	0.000002	0.000001	0.00000005	0.000003
Root Veg. Intake/Adult Soil Ingestion	0.0000009	0.00000005	0.00006	1.1E-09	0.000007	4.7E-10	0.000000008	0.000002	0.000001	0.00000005	0.000003
Root Veg. Intake/Child Soil Ingestion	0.000001	0.00000005	0.0001	1.8E-09	0.00001	1.1E-09	0.00000002	0.000003	0.000003	0.0000001	0.000007
Fruit Intake/Application Rate	0.000002	0.0000001	0.0001	2.0E-09	0.00002	8.2E-10	0.00000001	0.000007	0.000003	0.00000009	0.000005
Fruit Intake/Application Frequency	0.000002	0.0000001	0.0001	2.1E-09	0.00003	8.5E-10	0.00000001	0.000007	0.000003	0.00000009	0.000005
Fruit Intake/Constituent Concentration	0.00004	0.0000004	0.0003	1.0E-08	0.00005	2.5E-09	0.00000002	0.00004	0.000003	0.0000002	0.0004
Fruit Intake/Tilling Depth	0.000001	0.00000009	0.00007	1.3E-09	0.00002	5.2E-10	0.000000009	0.000005	0.000001	0.00000005	0.000004
Fruit Intake/Adult Soil Ingestion	0.000001	0.00000005	0.00007	1.3E-09	0.00002	5.2E-10	0.000000008	0.000005	0.000001	0.00000005	0.000004
Fruit Intake/Child Soil Ingestion	0.000001	0.00000006	0.0001	2.0E-09	0.00002	1.2E-09	0.00000002	0.000006	0.000003	0.0000001	0.000008
Appplication Rate/Application Frequency	0.000002	0.0000001	0.0002	2.8E-09	0.00002	1.2E-09	0.00000002	0.000004	0.000004	0.0000001	0.000008
Appplication Rate/Constituent Concentration	0.00005	0.0000006	0.0005	1.4E-08	0.00004	3.6E-09	0.00000003	0.00002	0.000004	0.0000002	0.0006
Appplication Rate/Tilling Depth	0.000001	0.0000001	0.0001	1.7E-09	0.00001	7.4E-10	0.00000002	0.000002	0.000002	0.00000008	0.000005
Appplication Rate/Adult Soil Ingestion	0.000001	0.00000008	0.0001	1.7E-09	0.00001	7.4E-10	0.00000001	0.000002	0.000002	0.00000008	0.000005
Appplication Rate/Child Soil Ingestion	0.000003	0.00000009	0.0003	2.9E-09	0.00002	1.8E-09	0.00000004	0.000004	0.000005	0.0000001	0.00001
Appplication Frequency/Constituent Concentration	0.00005	0.0000006	0.0005	1.4E-08	0.00004	3.7E-09	0.00000003	0.00002	0.000004	0.0000002	0.0007
Appplication Frequency/Tilling Depth	0.000001	0.0000001	0.0001	1.7E-09	0.00001	7.6E-10	0.00000001	0.000002	0.000002	0.00000008	0.000005
Appplication Frequency/Adult Soil Ingestion	0.000001	0.00000008	0.0001	1.7E-09	0.00001	7.7E-10	0.00000001	0.000002	0.000002	0.00000008	0.000005
Appplication Frequency/Child Soil Ingestion	0.000003	0.00000009	0.0003	2.9E-09	0.00002	1.9E-09	0.00000003	0.000005	0.000005	0.0000001	0.00001
Constituent Concentration/Tilling Depth	0.00003	0.0000005	0.0003	8.5E-09	0.00003	2.3E-09	0.00000002	0.00001	0.000002	0.0000001	0.0003
Constituent Concentration/Adult Soil Ingestion	0.00003	0.0000003	0.0003	8.5E-09	0.00003	2.3E-09	0.00000002	0.00001	0.000002	0.0000001	0.0003
Constituent Concentration/Child Soil Ingestion	0.00006	0.00000036	0.0006	1.4E-08	0.00006	5.6E-09	0.00000005	0.00002	0.000005	0.0000002	0.0009
Tilling Depth/Adult Soil Ingestion	0.0000008	0.00000007	0.00006	1.1E-09	0.00001	4.7E-10	0.000000009	0.000002	0.000001	0.00000005	0.000003
Tilling Depth/Child Soil Ingestion	0.000001	0.00000007	0.0001	1.8E-09	0.00002	1.2E-09	0.00000002	0.000003	0.000003	0.0000001	0.000007
Adult Soil Ingestion/Child Soil Ingestion	0.000001	0.00000005	0.0001	1.8E-09	0.00001	1.1E-09	0.00000002	0.000003	0.000003	0.0000001	0.000007

Table H1-7c Adult Resident Individual Risk from All Ingestion Pathways for FBC Wastes Applied as Agricultural Soil Amendment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Central Tendency	0.00000001	0.00000000006	0.000001	5.8E-12	0.0000001	5.5E-12	0.0000000002	0.00000002	0.00000003	0.0000000008	0.00000006
Single High-end Parameter											
Long Exposure	0.00000001	0.00000000005	0.000001	5.6E-11	0.0000001	5.2E-11	0.0000000002	0.00000002	0.00000003	0.000000001	0.00000006
Application Rate	0.00000002	0.0000000001	0.000002	9.4E-12	0.0000002	8.8E-12	0.0000000003	0.00000003	0.00000005	0.000000001	0.0000001
Application Frequency	0.00000002	0.0000000001	0.000002	9.5E-12	0.0000002	9.1E-12	0.0000000003	0.00000003	0.00000005	0.000000001	0.0000001
Constituent Concentration	0.0000004	0.0000000004	0.000005	4.7E-11	0.0000004	2.7E-11	0.0000000005	0.0000001	0.00000005	0.000000002	0.000008
Tilling Depth	0.00000001	0.00000000009	0.000001	5.8E-12	0.0000001	5.6E-12	0.0000000002	0.00000002	0.00000003	0.000000001	0.00000006
Adult Soil Ingestion	0.00000003	0.0000000001	0.000002	1.3E-11	0.0000003	1.2E-11	0.0000000004	0.00000004	0.00000006	0.000000002	0.0000001
Double High-end Parameters											
Application Rate/Long Exposure	0.00000002	0.00000000009	0.000002	9.1E-11	0.0000002	8.4E-11	0.0000000003	0.00000003	0.00000005	0.000000001	0.00000009
Application Frequency/Long Exposure	0.00000002	0.00000000009	0.000002	9.3E-11	0.0000002	8.7E-11	0.0000000003	0.00000003	0.00000005	0.000000001	0.0000001
Constituent Concentration/Long Exposure	0.0000004	0.0000000003	0.000005	4.5E-10	0.0000004	2.6E-10	0.0000000004	0.0000001	0.00000005	0.000000002	0.000008
Tilling Depth/Long Exposure	0.00000001	0.00000000008	0.000001	5.6E-11	0.0000001	5.4E-11	0.0000000002	0.00000002	0.00000003	0.000000001	0.00000006
Adult Soil Ingestion/Long Exposure	0.00000003	0.0000000001	0.000002	1.2E-10	0.0000002	1.2E-10	0.0000000004	0.00000004	0.00000006	0.000000002	0.0000001
Appplication Rate/Application Frequency	0.00000003	0.0000000002	0.000003	1.6E-11	0.0000003	1.5E-11	0.0000000005	0.00000005	0.00000008	0.000000002	0.0000002
Appplication Rate/Constituent Concentration	0.0000007	0.0000000006	0.000008	7.7E-11	0.0000006	4.4E-11	0.0000000008	0.0000002	0.00000008	0.000000003	0.00001
Appplication Rate/Tilling Depth	0.00000002	0.0000000001	0.000002	9.5E-12	0.0000002	8.9E-12	0.0000000004	0.00000003	0.00000005	0.000000001	0.0000001
Application Rate/Adult Soil Ingestion	0.00000005	0.0000000002	0.000004	2.1E-11	0.0000004	1.9E-11	0.0000000007	0.00000007	0.0000001	0.000000003	0.0000002
Appplication Frequency/Constituent Concentration	0.0000007	0.0000000006	0.000008	7.7E-11	0.0000007	4.5E-11	0.0000000007	0.0000002	0.00000008	0.000000003	0.00001
Appplication Frequency/Tilling Depth	0.00000002	0.0000000001	0.000002	9.6E-12	0.0000002	9.2E-12	0.0000000003	0.00000003	0.00000005	0.000000001	0.0000001
Application Frequency/Adult Soil Ingestion	0.00000005	0.0000000002	0.000004	2.1E-11	0.0000004	2.0E-11	0.0000000007	0.00000007	0.0000001	0.000000003	0.0000002
Constituent Concentration/Tilling Depth	0.0000005	0.0000000006	0.000005	4.7E-11	0.0000005	2.8E-11	0.0000000005	0.0000002	0.00000005	0.000000002	0.000008
Constituent Concentration/Adult Soil Ingestion	0.000001	0.0000000008	0.00001	1.0E-10	0.0000009	6.0E-11	0.000000001	0.0000003	0.0000001	0.000000005	0.00002
Tilling Depth/Adult Soil Ingestion	0.00000003	0.0000000002	0.000002	1.3E-11	0.0000003	1.2E-11	0.0000000005	0.00000005	0.00000006	0.000000002	0.0000001

Table H1-7d Home Gardener Individual Risk from All Ingestion Pathways for FBC Wastes Applied as Agricultural Soil Amendment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Central Tendency	0.00000003	0.000000001	0.000001	1.6E-11	0.0000009	8.2E-12	0.0000000002	0.0000003	0.00000004	0.000000002	0.00000008
Single High-end Parameter											
Long Exposure	0.00000003	0.000000001	0.000001	1.6E-10	0.0000009	7.9E-11	0.0000000002	0.0000003	0.00000004	0.000000001	0.00000008
Exposed Veg. Intake	0.00000007	0.000000004	0.000002	3.6E-11	0.000003	1.4E-11	0.0000000002	0.000001	0.00000006	0.000000003	0.0000001
Root Veg.Intake	0.00000003	0.000000001	0.000001	1.8E-11	0.000001	8.6E-12	0.0000000002	0.0000004	0.00000005	0.000000002	0.00000009
Fruit Intake	0.00000009	0.000000005	0.000002	4.5E-11	0.000003	1.6E-11	0.0000000002	0.000001	0.00000008	0.000000004	0.0000001
Application Rate	0.00000005	0.000000002	0.000002	2.7E-11	0.000002	1.3E-11	0.0000000003	0.0000006	0.00000007	0.000000002	0.0000001
Application Frequency	0.00000005	0.000000002	0.000002	2.7E-11	0.000002	1.4E-11	0.0000000003	0.0000006	0.00000007	0.000000002	0.0000001
Constituent Concentration	0.000001	0.000000009	0.000006	1.3E-10	0.000003	4.1E-11	0.0000000005	0.000002	0.00000007	0.000000004	0.00001
Tilling Depth	0.00000003	0.000000002	0.000001	1.6E-11	0.000001	8.3E-12	0.0000000002	0.0000003	0.00000004	0.000000002	0.00000008
Adult Soil Ingestion	0.00000005	0.000000001	0.000002	2.3E-11	0.000001	1.5E-11	0.0000000004	0.0000004	0.00000007	0.000000003	0.0000001
Double High-end Parameters											
Exposed Veg. Intake/Long Exposure	0.00000007	0.000000003	0.000002	3.5E-10	0.000003	1.3E-10	0.0000000002	0.000001	0.00000006	0.000000003	0.0000001
Root Veg. Intake/Long Exposure	0.00000003	0.000000001	0.000001	1.8E-10	0.000001	8.2E-11	0.0000000002	0.0000004	0.00000005	0.000000001	0.00000009
Fruit Intake/Long Exposure	0.00000009	0.000000004	0.000002	4.3E-10	0.000003	1.5E-10	0.0000000002	0.000001	0.00000008	0.000000004	0.0000001
Application Rate/Long Exposure	0.00000005	0.000000002	0.000002	2.6E-10	0.000001	1.3E-10	0.0000000003	0.0000006	0.00000007	0.000000002	0.0000001
Application Frequency/Long Exposure	0.00000005	0.000000002	0.000002	2.6E-10	0.000002	1.3E-10	0.0000000003	0.0000006	0.00000007	0.000000002	0.0000001
Constituent Concentration/Long Exposure	0.000001	0.000000008	0.000006	1.3E-09	0.000003	3.9E-10	0.0000000004	0.000002	0.00000007	0.000000004	0.00001
Tilling Depth/Long Exposure	0.00000003	0.000000002	0.000001	1.6E-10	0.000001	8.0E-11	0.0000000002	0.0000003	0.00000004	0.000000001	0.00000008
Adult Soil Ingestion/Long Exposure	0.00000005	0.000000001	0.000002	2.2E-10	0.000001	1.4E-10	0.0000000004	0.0000004	0.00000007	0.000000003	0.0000001
Exposed Veg. Intake/Root Veg. Intake	0.00000008	0.000000004	0.000002	3.8E-11	0.000003	1.4E-11	0.0000000002	0.000001	0.00000006	0.000000003	0.0000001
Exposed Veg. Intake/Fruit Intake	0.0000001	0.000000007	0.000002	6.5E-11	0.000005	2.1E-11	0.0000000002	0.000002	0.00000009	0.000000006	0.0000002
Exposed Veg. Intake/Application Rate	0.0000001	0.000000005	0.000003	5.9E-11	0.000004	2.2E-11	0.0000000003	0.000001	0.0000001	0.000000005	0.0000002
Exposed Veg. Intake/Application Frequency	0.0000001	0.000000005	0.000003	6.0E-11	0.000004	2.2E-11	0.0000000003	0.000001	0.0000001	0.000000005	0.0000002
Exposed Veg. Intake/Constituent Concentration	0.000003	0.00000003	0.000008	2.9E-10	0.000009	6.7E-11	0.0000000005	0.000007	0.0000001	0.000000008	0.00001
Exposed Veg. Intake/Tilling Depth	0.00000007	0.000000005	0.000002	3.7E-11	0.000003	1.4E-11	0.0000000002	0.000001	0.00000007	0.000000003	0.0000001
Exposed Veg. Intake/Adult Soil Ingestion	0.00000009	0.000000004	0.000003	4.3E-11	0.000003	2.0E-11	0.0000000004	0.000001	0.00000009	0.000000004	0.0000002
Root Veg. Intake/Fruit Intake	0.00000009	0.000000005	0.000002	4.7E-11	0.000004	1.6E-11	0.0000000002	0.000001	0.00000008	0.000000004	0.0000001
Root Veg. Intake/Application Rate	0.00000006	0.000000002	0.000002	3.0E-11	0.000002	1.4E-11	0.0000000003	0.0000006	0.00000008	0.000000002	0.0000002
Root Veg. Intake/Application Frequency	0.00000006	0.000000002	0.000002	3.0E-11	0.000002	1.4E-11	0.0000000003	0.0000006	0.00000008	0.000000002	0.0000002
Root Veg. Intake/Constituent Concentration	0.000001	0.00000001	0.000006	1.5E-10	0.000004	4.3E-11	0.0000000005	0.000003	0.00000008	0.000000004	0.00001
Root Veg. Intake/Tilling Depth	0.00000003	0.000000002	0.000001	1.9E-11	0.000001	8.7E-12	0.0000000002	0.0000004	0.00000005	0.000000002	0.00000009
Root Veg. Intake/Adult Soil Ingestion	0.00000005	0.000000002	0.000002	2.5E-11	0.000001	1.5E-11	0.0000000004	0.0000004	0.00000008	0.000000003	0.0000001
Fruit Intake/Application Rate	0.0000001	0.000000007	0.000003	7.3E-11	0.000005	2.5E-11	0.0000000003	0.000002	0.0000001	0.000000006	0.0000002
Fruit Intake/Application Frequency	0.0000001	0.000000007	0.000003	7.4E-11	0.000006	2.6E-11	0.0000000003	0.000002	0.0000001	0.000000006	0.0000002
Fruit Intake/Constituent Concentration	0.000003	0.00000003	0.000008	3.7E-10	0.00001	7.9E-11	0.0000000005	0.000009	0.0000001	0.00000001	0.00002
Fruit Intake/Tilling Depth	0.00000009	0.000000007	0.000002	4.5E-11	0.000005	1.6E-11	0.0000000002	0.000001	0.00000008	0.000000004	0.0000001
Fruit Intake/Adult Soil Ingestion	0.0000001	0.000000005	0.000003	5.2E-11	0.000004	2.2E-11	0.0000000004	0.000001	0.0000001	0.000000005	0.0000002
Appplication Rate/Application Frequency	0.00000008	0.000000003	0.000004	4.4E-11	0.000002	2.2E-11	0.0000000005	0.0000009	0.0000001	0.000000004	0.0000003
Appplication Rate/Constituent Concentration	0.000002	0.00000001	0.00001	2.2E-10	0.000006	6.5E-11	0.0000000008	0.000003	0.0000001	0.000000006	0.00001
Appplication Rate/Tilling Depth	0.00000005	0.000000003	0.000002	2.7E-11	0.000002	1.3E-11	0.0000000004	0.0000006	0.00000007	0.000000002	0.0000001
Application Rate/Adult Soil Intake	0.00000008	0.000000002	0.000004	3.8E-11	0.000002	2.4E-11	0.0000000007	0.0000006	0.0000001	0.000000004	0.0000002

Table H1-7d Home Gardener Individual Risk from All Ingestion Pathways for FBC Wastes Applied as Agricultural Soil Amendment

Parameters Set to High-end	Nickel	Silver	Thallium	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI	Cobalt	Vanadium
Appplication Frequency/Constituent Concentration	0.000002	0.00000001	0.00001	2.2E-10	0.000006	6.8E-11	0.0000000007	0.000004	0.0000001	0.000000006	0.00001
Appplication Frequency/Tilling Depth	0.00000005	0.000000003	0.000002	2.7E-11	0.000002	1.4E-11	0.0000000003	0.0000007	0.00000007	0.000000002	0.0000001
Application Frequency/Adult Soil Ingestion	0.00000008	0.000000002	0.000004	3.8E-11	0.000002	2.5E-11	0.0000000007	0.0000006	0.0000001	0.000000004	0.0000002
Constituent Concentration/Tilling Depth	0.000001	0.00000001	0.000006	1.3E-10	0.000004	4.1E-11	0.0000000005	0.000003	0.00000007	0.000000004	0.00001
Constiuent Concentration/Adult Soil Ingestion	0.000002	0.000000009	0.00001	1.9E-10	0.000004	7.4E-11	0.000000001	0.000002	0.0000001	0.000000007	0.00002
Tilling Depth/Adult Soil Ingestion	0.00000005	0.000000002	0.000002	2.3E-11	0.000001	1.5E-11	0.0000000005	0.0000004	0.00000007	0.000000003	0.0000001

Table H1-7e Fisher Individual Risk from All Ingestion Pathways for FBC Wastes Applied as Agricultural Soil Amendment

Parameters Set to High-end	Nickel	Thallium	Arsenic	Beryllium	Cadmium	Chromium VI
Central Tendency	0.00000000001	0.00000009	6.1E-14	1.5E-13	0.000000003	0.0000000001
Single High-end Parameter						
Long Exposure	0.00000000001	0.00000009	5.9E-13	1.4E-12	0.000000003	0.0000000001
Fish Intake	0.00000000008	0.0000006	3.9E-13	9.4E-13	0.00000002	0.0000000009
Application Rate	0.00000000002	0.0000001	1.0E-13	2.4E-13	0.000000004	0.0000000002
Application Frequency	0.00000000002	0.0000002	1.0E-13	2.4E-13	0.000000005	0.0000000002
Constituent Concentration	0.0000000004	0.0000004	5.0E-13	7.3E-13	0.00000002	0.0000000002
Tilling Depth	0.00000000001	0.00000009	6.2E-14	1.5E-13	0.000000003	0.0000000001
Double High-end Parameters						
Fish Intake/Long Exposure	0.00000000008	0.0000006	3.8E-12	9.0E-12	0.00000002	0.0000000008
Application Rate/Long Exposure	0.00000000002	0.0000001	9.6E-13	2.3E-12	0.000000004	0.0000000002
Application Frequency/Long Exposure	0.00000000002	0.0000001	9.8E-13	2.3E-12	0.000000004	0.0000000002
Constituent Con./Long Exposure	0.0000000004	0.0000004	4.8E-12	7.0E-12	0.00000002	0.0000000002
Tilling Depth/Long Exposure	0.00000000001	0.00000009	5.9E-13	1.4E-12	0.000000003	0.0000000001
Fish Intake/Application Rate	0.0000000001	0.0000009	6.4E-13	1.5E-12	0.00000003	0.000000001
Fish Intake/Application Frequency	0.0000000001	0.000001	6.4E-13	1.6E-12	0.00000003	0.000000001
Fish Intake/Constituent Concentration	0.000000003	0.000003	3.2E-12	4.7E-12	0.0000001	0.000000001
Fish Intake/Tilling Depth	0.00000000008	0.0000006	3.9E-13	9.5E-13	0.00000002	0.0000000009
Appplication Rate/Application Frequency	0.00000000003	0.0000002	1.7E-13	3.9E-13	0.000000007	0.0000000004
Appplication Rate/Constituent Concentration	0.0000000007	0.0000007	8.2E-13	1.2E-12	0.00000003	0.0000000004
Appplication Rate/Tilling Depth	0.00000000002	0.0000001	1.0E-13	2.4E-13	0.000000005	0.0000000002
Appplication Frequency/Constituent Concentration	0.0000000007	0.0000007	8.2E-13	1.2E-12	0.00000003	0.0000000004
Appplication Frequency/Tilling Depth	0.00000000002	0.0000002	1.0E-13	2.5E-13	0.000000005	0.0000000002
Constituent Concentration/Tilling Depth	0.0000000005	0.0000004	5.0E-13	7.4E-13	0.00000002	0.0000000002

Table H2-1a Farmer Individual Risk from Inhalation for Utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	2.9E-09	1.5E-08	0.002	4.1E-09	0.00001	2.1E-09	1.4E-07
Single High-end Parameter							
Long Exposure	1.2E-08	6.0E-08	0.002	1.6E-08	0.00001	8.6E-09	5.8E-07
Constituent Conc.	7.5E-09	1.3E-07	0.02	7.6E-09	0.00003	8.6E-09	7.1E-07
Meteorological Location	2.5E-09	1.3E-08	0.002	3.4E-09	0.000009	1.8E-09	1.2E-07
Distance To Receptor	1.1E-08	5.4E-08	0.008	1.5E-08	0.00004	7.7E-09	5.2E-07
WMU Area	1.4E-08	7.4E-08	0.01	2.0E-08	0.00005	1.0E-08	7.0E-07
Double High-end Parameters							
Constituent Conc./Long Exposure	3.0E-08	5.4E-07	0.02	3.0E-08	0.00003	3.4E-08	*2.8E-06*
Meteorological Location/Long Exposure	9.8E-09	5.1E-08	0.002	1.4E-08	0.000009	7.2E-09	4.9E-07
Distance to Receptor/Long Exposure	4.2E-08	2.2E-07	0.008	5.9E-08	0.00004	3.1E-08	*2.1E-06*
WMU Area/Long Exposure	5.7E-08	2.9E-07	0.01	8.0E-08	0.00005	4.2E-08	*2.8E-06*
Waste Concentration/ Meteorological Location	6.4E-09	1.1E-07	0.02	6.4E-09	0.00003	7.3E-09	6.0E-07
Waste Concentration/ Distance to Receptor	2.7E-08	4.9E-07	0.09	2.7E-08	0.0001	3.1E-08	*2.6E-06*
Waste Concentration/ WMU Area	3.7E-08	6.6E-07	0.1	3.7E-08	0.0002	4.2E-08	***3.5E-06***
Meteorological Location/Distance to Receptor	8.6E-09	4.5E-08	0.007	1.2E-08	0.00003	6.4E-09	4.3E-07
Meteorological Location/WMU Area	1.3E-08	6.6E-08	0.01	1.8E-08	0.00005	9.4E-09	6.3E-07
Distance to Receptor/WMU Area	5.2E-08	2.7E-07	0.04	7.2E-08	0.0002	3.8E-08	*2.6E-06*

Table H2-1b Child of Farmer Individual Risk from Inhalation for Utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	2.1E-09	1.1E-08	0.002	3.0E-09	0.00001	1.6E-09	1.1E-07
Single High-end Parameter							
Long Exposure	5.3E-09	2.7E-08	0.002	7.4E-09	0.00001	3.9E-09	2.6E-07
Constituent Conc.	5.5E-09	9.9E-08	0.02	5.6E-09	0.00003	6.3E-09	5.2E-07
Meteorological Location	1.8E-09	9.4E-09	0.002	2.5E-09	0.000009	1.3E-09	9.0E-08
Distance To Receptor	7.7E-09	4.0E-08	0.008	1.1E-08	0.00004	5.7E-09	3.8E-07
WMU Area	1.0E-08	5.4E-08	0.01	1.5E-08	0.00005	7.7E-09	5.2E-07
Double High-end Parameters							
Constituent Conc./Long Exposure	1.4E-08	2.4E-07	0.02	1.4E-08	0.00003	1.6E-08	*1.3E-06*
Meteorological Location/Long Exposure	4.5E-09	2.3E-08	0.002	6.2E-09	0.000009	3.3E-09	2.2E-07
Distance to Receptor/Long Exposure	1.9E-08	9.9E-08	0.008	2.7E-08	0.00004	1.4E-08	9.5E-07
WMU Area/Long Exposure	2.6E-08	1.3E-07	0.01	3.6E-08	0.00005	1.9E-08	*1.3E-06*
Waste Concentration/ Meteorological Location	4.7E-09	8.3E-08	0.02	4.7E-09	0.00003	5.4E-09	4.4E-07
Waste Concentration/ Distance to Receptor	2.0E-08	3.6E-07	0.09	2.0E-08	0.0001	2.3E-08	*1.9E-06*
Waste Concentration/ WMU Area	2.7E-08	4.8E-07	0.1	2.7E-08	0.0002	3.1E-08	***2.5E-06***
Meteorological Location/Distance to Receptor	6.4E-09	3.3E-08	0.007	8.9E-09	0.00003	4.7E-09	3.2E-07
Meteorological Location/WMU Area	9.4E-09	4.9E-08	0.01	1.3E-08	0.00005	6.9E-09	4.7E-07
Distance to Receptor/WMU Area	3.8E-08	2.0E-07	0.04	5.3E-08	0.0002	2.8E-08	*1.9E-06*

Table H2-1c Adult Resident and Home Gardener Individual Risk from Inhalation for Utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	9.6E-10	5.0E-09	0.002	1.3E-09	0.00001	7.1E-10	4.8E-08
Single High-end Parameter							
Long Exposure	9.4E-09	4.9E-08	0.002	1.3E-08	0.00001	6.9E-09	4.7E-07
Constituent Conc.	2.5E-09	4.4E-08	0.02	2.5E-09	0.00003	2.8E-09	2.3E-07
Meteorological Location	8.1E-10	4.2E-09	0.002	1.1E-09	0.000009	6.0E-10	4.0E-08
Distance To Receptor	3.5E-09	1.8E-08	0.008	4.9E-09	0.00004	2.6E-09	1.7E-07
WMU Area	4.7E-09	2.4E-08	0.01	6.6E-09	0.00005	3.5E-09	2.3E-07
Double High-end Parameters							
Constituent Conc./Long Exposure	2.4E-08	4.3E-07	0.02	2.5E-08	0.00003	2.8E-08	***2.3E-06***
Meteorological Location/Long Exposure	7.9E-09	4.1E-08	0.002	1.1E-08	0.000009	5.9E-09	3.9E-07
Distance to Receptor/Long Exposure	3.4E-08	1.8E-07	0.008	4.8E-08	0.00004	2.5E-08	*1.7E-06*
WMU Area/Long Exposure	4.6E-08	2.4E-07	0.01	6.4E-08	0.00005	3.4E-08	***2.3E-06***
Waste Concentration/ Meteorological Location	2.1E-09	3.7E-08	0.02	2.1E-09	0.00003	2.4E-09	2.0E-07
Waste Concentration/ Distance to Receptor	9.0E-09	1.6E-07	0.09	9.1E-09	0.0001	1.0E-08	8.4E-07
Waste Concentration/ WMU Area	1.2E-08	2.2E-07	0.1	1.2E-08	0.0002	1.4E-08	*1.1E-06*
Meteorological Location/Distance to Receptor	2.8E-09	1.5E-08	0.007	4.0E-09	0.00003	2.1E-09	1.4E-07
Meteorological Location/WMU Area	4.2E-09	2.2E-08	0.01	5.9E-09	0.00005	3.1E-09	2.1E-07
Distance to Receptor/WMU Area	1.7E-08	8.8E-08	0.04	2.4E-08	0.0002	1.3E-08	8.5E-07

Table H2-2a Farmer Individual Risk from Inhalation for Utility Coal Co-managed Wastes Managed in Dewatered Surface Impoundment

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	1.89E-09	1E-08	0.001	2.65E-09	0.000007	1.4E-09	9.4E-08
Single High-end Parameter							
Long Exposure	7.57E-09	4E-08	0.001	1.06E-08	0.000007	5.6E-09	3.8E-07
Constituent Conc.	4.91E-09	9E-08	0.02	4.95E-09	0.00002	5.6E-09	4.6E-07
Meteorological Location	9.05E-09	5E-08	0.007	1.27E-08	0.00003	6.7E-09	4.5E-07
Distance To Receptor	5.49E-09	3E-08	0.004	7.7E-09	0.00002	4.1E-09	2.7E-07
WMU Area	4.03E-09	2E-08	0.003	5.65E-09	0.00001	3.0E-09	2.0E-07
Double High-end Parameters							
Constituent Conc./Long Exposure	1.96E-08	3E-07	0.02	1.98E-08	0.00002	2.2E-08	*1.8E-06*
Meteorological Location/Long Exposure	3.62E-08	2E-07	0.007	5.07E-08	0.00003	2.7E-08	*1.8E-06*
Distance to Receptor/Long Exposure	2.2E-08	1E-07	0.004	3.08E-08	0.00002	1.6E-08	*1.1E-06*
WMU Area/Long Exposure	1.61E-08	8E-08	0.003	2.26E-08	0.00001	1.2E-08	8.0E-07
Waste Concentration/ Meteorological Location	2.35E-08	4E-07	0.08	2.37E-08	0.0001	2.7E-08	***2.2E-06***
Waste Concentration/ Distance to Receptor	1.42E-08	3E-07	0.05	1.44E-08	0.00006	1.6E-08	*1.3E-06*
Waste Concentration/ WMU Area	1.04E-08	2E-07	0.03	1.05E-08	0.00004	1.2E-08	9.8E-07
Meteorological Location/Distance to Receptor	2.59E-08	1E-07	0.02	3.63E-08	0.00009	1.9E-08	*1.3E-06*
Meteorological Location/WMU Area	1.93E-08	1E-07	0.02	2.71E-08	0.00007	1.4E-08	9.6E-07
Distance to Receptor/WMU Area	8.32E-09	4E-08	0.007	1.17E-08	0.00003	6.1E-09	4.1E-07

Table H2-2b Child of Farmer Individual Risk from Inhalation for Utility Coal Co-managed Wastes Managed in Dewatered Surface Impoundment

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	1.4E-09	7.2E-09	0.001	2.0E-09	0.000007	1.0E-09	6.9E-08
Single High-end Parameter							
Long Exposure	3.4E-09	1.8E-08	0.001	4.8E-09	0.000007	2.5E-09	1.7E-07
Constituent Conc.	3.6E-09	6.4E-08	0.02	3.6E-09	0.00002	4.1E-09	3.4E-07
Meteorological Location	6.7E-09	3.5E-08	0.007	9.3E-09	0.00003	4.9E-09	3.3E-07
Distance To Receptor	4.0E-09	2.1E-08	0.004	5.7E-09	0.00002	3.0E-09	2.0E-07
WMU Area	3.0E-09	1.5E-08	0.003	4.2E-09	0.00001	2.2E-09	1.5E-07
Double High-end Parameters							
Constituent Conc./Long Exposure	8.9E-09	1.6E-07	0.02	9.0E-09	0.00002	1.0E-08	8.4E-07
Meteorological Location/Long Exposure	1.6E-08	8.5E-08	0.007	2.3E-08	0.00003	1.2E-08	8.2E-07
Distance to Receptor/Long Exposure	1.0E-08	5.2E-08	0.004	1.4E-08	0.00002	7.3E-09	4.9E-07
WMU Area/Long Exposure	7.3E-09	3.8E-08	0.003	1.0E-08	0.00001	5.4E-09	3.6E-07
Waste Concentration/ Meteorological Location	1.7E-08	3.1E-07	0.08	1.7E-08	0.0001	2.0E-08	***1.6E-06***
Waste Concentration/ Distance to Receptor	1.0E-08	1.9E-07	0.05	1.1E-08	0.00006	1.2E-08	9.8E-07
Waste Concentration/ WMU Area	7.7E-09	1.4E-07	0.03	7.7E-09	0.00004	8.8E-09	7.2E-07
Meteorological Location/Distance to Receptor	1.9E-08	9.9E-08	0.02	2.7E-08	0.00009	1.4E-08	9.5E-07
Meteorological Location/WMU Area	1.4E-08	7.4E-08	0.02	2.0E-08	0.00007	1.0E-08	7.1E-07
Distance to Receptor/WMU Area	6.1E-09	3.2E-08	0.007	8.6E-09	0.00003	4.5E-09	3.0E-07

Table H2-2c Adult Resident and Home Gardener Individual Risk from Inhalation for Utility Coal Co-managed Wastes Managed in Dewatered Surface Impoundment

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	6.2E-10	3.2E-09	0.001	8.8E-10	0.000007	4.6E-10	3.1E-08
Single High-end Parameter							
Long Exposure	6.1E-09	3.2E-08	0.001	8.6E-09	0.000007	4.5E-09	3.0E-07
Constituent Conc.	1.6E-09	2.9E-08	0.02	1.6E-09	0.00002	1.9E-09	1.5E-07
Meteorological Location	3.0E-09	1.5E-08	0.007	4.2E-09	0.00003	2.2E-09	1.5E-07
Distance To Receptor	1.8E-09	9.4E-09	0.004	2.5E-09	0.00002	1.3E-09	9.0E-08
WMU Area	1.3E-09	6.9E-09	0.003	1.9E-09	0.00001	9.8E-10	6.6E-08
Double High-end Parameters							
Constituent Conc./Long Exposure	1.6E-08	2.8E-07	0.02	1.6E-08	0.00002	1.8E-08	***1.5E-06***
Meteorological Location/Long Exposure	2.9E-08	1.5E-07	0.007	4.1E-08	0.00003	2.2E-08	***1.5E-06***
Distance to Receptor/Long Exposure	1.8E-08	9.2E-08	0.004	2.5E-08	0.00002	1.3E-08	8.8E-07
WMU Area/Long Exposure	1.3E-08	6.7E-08	0.003	1.8E-08	0.00001	9.6E-09	6.5E-07
Waste Concentration/ Meteorological Location	7.7E-09	1.4E-07	0.08	7.8E-09	0.0001	8.9E-09	7.3E-07
Waste Concentration/ Distance to Receptor	4.7E-09	8.4E-08	0.05	4.7E-09	0.00006	5.4E-09	4.4E-07
Waste Concentration/ WMU Area	3.4E-09	6.1E-08	0.03	3.5E-09	0.00004	3.9E-09	3.2E-07
Meteorological Location/Distance to Receptor	8.6E-09	4.4E-08	0.02	1.2E-08	0.00009	6.3E-09	4.3E-07
Meteorological Location/WMU Area	6.4E-09	3.3E-08	0.02	8.9E-09	0.00007	4.7E-09	3.2E-07
Distance to Receptor/WMU Area	2.7E-09	1.4E-08	0.007	3.8E-09	0.00003	2.0E-09	1.4E-07

Table H2-3a Farmer Individual Risk from Inhalation for Utility Oil Co-Managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Boron	Cadmium	Chromium VI
Central Tendency	9.5E-09	4.1E-10	0.00002	0.0000003	5.8E-11	2.3E-08
Single High-end Parameter						
Long Exposure	3.8E-08	1.6E-09	0.00002	0.0000003	2.3E-10	9.4E-08
Constituent Conc.	2.8E-08	2.2E-08	0.00007	0.0000003	2.2E-10	7.0E-08
Meteorological Location	8.0E-09	3.2E-10	0.00001	0.0000003	3.0E-11	2.0E-08
Distance To Receptor	6.9E-08	2.8E-09	0.0001	0.000002	2.6E-10	1.7E-07
WMU Area	1.1E-07	8.8E-08	0.00007	0.0000003	8.7E-10	2.8E-07
Double High-end Parameters						
Constituent Conc./Long Exposure	3.2E-08	1.3E-09	0.00001	0.0000003	1.2E-10	7.9E-08
Meteorological Location/Long Exposure	2.8E-07	1.1E-08	0.0001	0.000002	1.0E-09	6.8E-07
Distance to Receptor/Long Exposure	2.4E-08	1.8E-08	0.00006	0.0000003	1.8E-10	5.9E-08
WMU Area/Long Exposure	2.0E-07	1.6E-07	0.0005	0.000002	1.6E-09	5.1E-07
Waste Concentration/ Meteorological Location	9.5E-09	4.1E-10	0.00002	0.0000003	5.8E-11	2.3E-08
Waste Concentration/ Distance to Receptor	8.0E-09	3.2E-10	0.00001	0.0000003	3.0E-11	2.0E-08
Waste Concentration/ WMU Area	6.9E-08	2.8E-09	0.0001	0.000002	2.6E-10	1.7E-07
Meteorological Location/Distance to Receptor	8.0E-09	3.2E-10	0.00001	0.0000003	3.0E-11	2.0E-08
Meteorological Location/WMU Area	6.9E-08	2.8E-09	0.0001	0.000002	2.6E-10	1.7E-07
Distance to Receptor/WMU Area	5.9E-08	2.4E-09	0.0001	0.000002	2.2E-10	1.5E-07

Table H2-3b Child of Farmer Individual Risk from Inhalation for Utility Oil Co-Managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Boron	Cadmium	Chromium VI
Central Tendency	7.0E-09	3.0E-10	0.00002	0.0000003	4.3E-11	1.7E-08
Single High-end Parameter						
Long Exposure	1.7E-08	7.5E-10	0.00002	0.0000003	1.0E-10	4.3E-08
Constituent Conc.	2.1E-08	1.6E-08	0.00007	0.0000003	1.6E-10	5.2E-08
Meteorological Location	5.9E-09	2.4E-10	0.00001	0.0000003	2.2E-11	1.4E-08
Distance To Receptor	5.1E-08	2.0E-09	0.0001	0.000002	1.9E-10	1.3E-07
WMU Area	5.1E-08	4.0E-08	0.00007	0.0000003	3.9E-10	1.3E-07
Double High-end Parameters						
Constituent Conc./Long Exposure	1.4E-08	5.8E-10	0.00001	0.0000003	5.5E-11	3.6E-08
Meteorological Location/Long Exposure	1.3E-07	5.0E-09	0.0001	0.000002	4.7E-10	3.1E-07
Distance to Receptor/Long Exposure	1.7E-08	1.4E-08	0.00006	0.0000003	1.3E-10	4.3E-08
WMU Area/Long Exposure	1.5E-07	1.2E-07	0.0005	0.000002	1.2E-09	3.7E-07
Waste Concentration/ Meteorological Location	7.0E-09	3.0E-10	0.00002	0.0000003	4.3E-11	1.7E-08
Waste Concentration/ Distance to Receptor	5.9E-09	2.4E-10	0.00001	0.0000003	2.2E-11	1.4E-08
Waste Concentration/ WMU Area	5.1E-08	2.0E-09	0.0001	0.000002	1.9E-10	1.3E-07
Meteorological Location/Distance to Receptor	5.9E-09	2.4E-10	0.00001	0.0000003	2.2E-11	1.4E-08
Meteorological Location/WMU Area	5.1E-08	2.0E-09	0.0001	0.000002	1.9E-10	1.3E-07
Distance to Receptor/WMU Area	4.3E-08	1.7E-09	0.0001	0.000002	1.6E-10	1.1E-07

Table H2-3c Adult Resident and Home Gardener Individual Risk from Inhalation for Utility Oil Co-Managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Boron	Cadmium	Chromium VI
Central Tendency	3.1E-09	1.4E-10	0.00002	0.0000003	1.9E-11	7.7E-09
Single High-end Parameter						
Long Exposure	3.1E-08	1.3E-09	0.00002	0.0000003	1.9E-10	7.6E-08
Constituent Conc.	9.3E-09	7.3E-09	0.00007	0.0000003	7.2E-11	2.3E-08
Meteorological Location	2.6E-09	1.1E-10	0.00001	0.0000003	9.9E-12	6.5E-09
Distance To Receptor	2.3E-08	9.2E-10	0.0001	0.000002	8.6E-11	5.6E-08
WMU Area	9.1E-08	7.1E-08	0.00007	0.0000003	7.0E-10	2.3E-07
Double High-end Parameters						
Constituent Conc./Long Exposure	2.6E-08	1.0E-09	0.00001	0.0000003	9.7E-11	6.4E-08
Meteorological Location/Long Exposure	2.2E-07	9.0E-09	0.0001	0.000002	8.4E-10	5.5E-07
Distance to Receptor/Long Exposure	7.8E-09	6.1E-09	0.00006	0.0000003	6.0E-11	1.9E-08
WMU Area/Long Exposure	6.8E-08	5.3E-08	0.0005	0.000002	5.2E-10	1.7E-07
Waste Concentration/ Meteorological Location	3.1E-09	1.4E-10	0.00002	0.0000003	1.9E-11	7.7E-09
Waste Concentration/ Distance to Receptor	2.6E-09	1.1E-10	0.00001	0.0000003	9.9E-12	6.5E-09
Waste Concentration/ WMU Area	2.3E-08	9.2E-10	0.0001	0.000002	8.6E-11	5.6E-08
Meteorological Location/Distance to Receptor	2.6E-09	1.1E-10	0.00001	0.0000003	9.9E-12	6.5E-09
Meteorological Location/WMU Area	2.3E-08	9.2E-10	0.0001	0.000002	8.6E-11	5.6E-08
Distance to Receptor/WMU Area	1.9E-08	7.8E-10	0.0001	0.000002	7.3E-11	4.8E-08

Table H2-4a Farmer Individual Risk from Inhalation for Non-utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	5.2E-11	2.7E-10	0.00004	7.3E-11	0.0000002	3.8E-11	2.6E-09
Single High-end Parameter							
Long Exposure	1.6E-10	8.0E-10	0.00004	2.2E-10	0.0000002	1.1E-10	7.7E-09
Constituent Conc.	1.3E-10	2.4E-09	0.0004	1.4E-10	0.0000006	1.5E-10	1.3E-08
Meteorological Location	4.4E-11	2.3E-10	0.00003	6.2E-11	0.0000002	3.3E-11	2.2E-09
Distance To Receptor	4.0E-10	2.1E-09	0.0003	5.6E-10	0.000001	2.9E-10	2.0E-08
WMU Area	4.9E-10	2.6E-09	0.0004	6.9E-10	0.000002	3.6E-10	2.4E-08
Double High-end Parameters							
Constituent Conc./Long Exposure	4.0E-10	7.2E-09	0.0004	4.1E-10	0.0000006	4.6E-10	3.8E-08
Meteorological Location/Long Exposure	1.3E-10	6.9E-10	0.00003	1.9E-10	0.0000002	9.8E-11	6.6E-09
Distance to Receptor/Long Exposure	1.2E-09	6.2E-09	0.0003	1.7E-09	0.000001	8.8E-10	5.9E-08
WMU Area/Long Exposure	1.5E-09	7.7E-09	0.0004	2.1E-09	0.000002	1.1E-09	7.3E-08
Waste Concentration/ Meteorological Location	1.1E-10	2.0E-09	0.0004	1.2E-10	0.0000005	1.3E-10	1.1E-08
Waste Concentration/ Distance to Receptor	1.0E-09	1.8E-08	0.003	1.0E-09	0.000004	1.2E-09	9.7E-08
Waste Concentration/ WMU Area	1.3E-09	2.3E-08	0.004	1.3E-09	0.000005	1.5E-09	1.2E-07
Meteorological Location/Distance to Receptor	3.5E-10	1.8E-09	0.0003	4.9E-10	0.000001	2.6E-10	1.7E-08
Meteorological Location/WMU Area	3.9E-10	2.0E-09	0.0003	5.4E-10	0.000001	2.9E-10	1.9E-08
Distance to Receptor/WMU Area	2.8E-09	1.4E-08	0.002	3.9E-09	0.00001	2.0E-09	1.4E-07

Table H2-4b Child of Farmer Individual Risk from Inhalation for Non-utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	3.8E-11	2.0E-10	0.00004	5.3E-11	0.0000002	2.8E-11	1.9E-09
Single High-end Parameter							
Long Exposure	9.4E-11	4.9E-10	0.00004	1.3E-10	0.0000002	6.9E-11	4.7E-09
Constituent Conc.	9.9E-11	1.8E-09	0.0004	9.9E-11	0.0000006	1.1E-10	9.3E-09
Meteorological Location	3.2E-11	1.7E-10	0.00003	4.6E-11	0.0000002	2.4E-11	1.6E-09
Distance To Receptor	2.9E-10	1.5E-09	0.0003	4.1E-10	0.000001	2.2E-10	1.5E-08
WMU Area	3.6E-10	1.9E-09	0.0004	5.1E-10	0.000002	2.7E-10	1.8E-08
Double High-end Parameters							
Constituent Conc./Long Exposure	2.4E-10	4.3E-09	0.0004	2.5E-10	0.0000006	2.8E-10	2.3E-08
Meteorological Location/Long Exposure	8.0E-11	4.2E-10	0.00003	1.1E-10	0.0000002	5.9E-11	4.0E-09
Distance to Receptor/Long Exposure	7.2E-10	3.7E-09	0.0003	1.0E-09	0.000001	5.3E-10	3.6E-08
WMU Area/Long Exposure	8.9E-10	4.6E-09	0.0004	1.3E-09	0.000002	6.6E-10	4.4E-08
Waste Concentration/ Meteorological Location	8.4E-11	1.5E-09	0.0004	8.5E-11	0.0000005	9.6E-11	7.9E-09
Waste Concentration/ Distance to Receptor	7.6E-10	1.4E-08	0.003	7.7E-10	0.000004	8.7E-10	7.1E-08
Waste Concentration/ WMU Area	9.4E-10	1.7E-08	0.004	9.5E-10	0.000005	1.1E-09	8.8E-08
Meteorological Location/Distance to Receptor	2.6E-10	1.3E-09	0.0003	3.6E-10	0.000001	1.9E-10	1.3E-08
Meteorological Location/WMU Area	2.9E-10	1.5E-09	0.0003	4.0E-10	0.000001	2.1E-10	1.4E-08
Distance to Receptor/WMU Area	2.0E-09	1.1E-08	0.002	2.8E-09	0.00001	1.5E-09	1.0E-07

Table H2-4c Adult Resident and Home Gardener Individual Risk from Inhalation for Non-utility Coal Co-managed Wastes Managed in an Onsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	1.7E-11	8.9E-11	0.00004	2.4E-11	0.0000002	1.3E-11	8.5E-10
Single High-end Parameter							
Long Exposure	1.6E-10	8.0E-10	0.00004	2.2E-10	0.0000002	1.1E-10	7.7E-09
Constituent Conc.	4.4E-11	7.9E-10	0.0004	4.5E-11	0.0000006	5.1E-11	4.2E-09
Meteorological Location	1.5E-11	7.6E-11	0.00003	2.0E-11	0.0000002	1.1E-11	7.2E-10
Distance To Receptor	1.3E-10	6.8E-10	0.0003	1.8E-10	0.000001	9.7E-11	6.5E-09
WMU Area	1.6E-10	8.4E-10	0.0004	2.3E-10	0.000002	1.2E-10	8.1E-09
Double High-end Parameters							
Constituent Conc./Long Exposure	4.0E-10	7.2E-09	0.0004	4.1E-10	0.0000006	4.6E-10	3.8E-08
Meteorological Location/Long Exposure	1.3E-10	6.9E-10	0.00003	1.9E-10	0.0000002	9.8E-11	6.6E-09
Distance to Receptor/Long Exposure	1.2E-09	6.2E-09	0.0003	1.7E-09	0.000001	8.8E-10	5.9E-08
WMU Area/Long Exposure	1.5E-09	7.7E-09	0.0004	2.1E-09	0.000002	1.1E-09	7.3E-08
Waste Concentration/ Meteorological Location	3.8E-11	6.7E-10	0.0004	3.8E-11	0.0000005	4.3E-11	3.5E-09
Waste Concentration/ Distance to Receptor	3.4E-10	6.1E-09	0.003	3.4E-10	0.000004	3.9E-10	3.2E-08
Waste Concentration/ WMU Area	4.2E-10	7.5E-09	0.004	4.2E-10	0.000005	4.8E-10	4.0E-08
Meteorological Location/Distance to Receptor	1.2E-10	6.0E-10	0.0003	1.6E-10	0.000001	8.5E-11	5.7E-09
Meteorological Location/WMU Area	1.3E-10	6.6E-10	0.0003	1.8E-10	0.000001	9.5E-11	6.4E-09
Distance to Receptor/WMU Area	9.1E-10	4.7E-09	0.002	1.3E-09	0.00001	6.7E-10	4.5E-08

Table H2-5a Farmer Individual Risk from Inhalation for Non-utility Coal Co-managed Wastes Managed in Offsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	9.5E-11	4.9E-10	0.00007	1.3E-10	0.0000003	7.0E-11	4.7E-09
Single High-end Parameter							
Long Exposure	3.8E-10	2.0E-09	0.00007	5.3E-10	0.0000003	2.8E-10	1.9E-08
Constituent Conc.	2.5E-10	4.4E-09	0.0008	2.5E-10	0.000001	2.8E-10	2.3E-08
Meteorological Location	8.4E-11	4.3E-10	0.00007	1.2E-10	0.0000003	6.2E-11	4.2E-09
Distance To Receptor	4.9E-10	2.6E-09	0.0004	6.9E-10	0.000002	3.6E-10	2.5E-08
WMU Area	9.2E-10	4.8E-09	0.0007	1.3E-09	0.000003	6.8E-10	4.6E-08
Double High-end Parameters							
Constituent Conc./Long Exposure	9.9E-10	1.8E-08	0.0008	1.0E-09	0.000001	1.1E-09	9.3E-08
Meteorological Location/Long Exposure	3.4E-10	1.7E-09	0.00007	4.7E-10	0.0000003	2.5E-10	1.7E-08
Distance to Receptor/Long Exposure	2.0E-09	1.0E-08	0.0004	2.8E-09	0.000002	1.5E-09	9.8E-08
WMU Area/Long Exposure	3.7E-09	1.9E-08	0.0007	5.2E-09	0.000003	2.7E-09	1.8E-07
Waste Concentration/ Meteorological Location	2.2E-10	3.9E-09	0.0007	2.2E-10	0.0000009	2.5E-10	2.0E-08
Waste Concentration/ Distance to Receptor	1.3E-09	2.3E-08	0.004	1.3E-09	0.000005	1.5E-09	1.2E-07
Waste Concentration/ WMU Area	2.4E-09	4.3E-08	0.008	2.4E-09	0.00001	2.7E-09	2.2E-07
Meteorological Location/Distance to Receptor	4.6E-10	2.4E-09	0.0004	6.4E-10	0.000002	3.4E-10	2.3E-08
Meteorological Location/WMU Area	8.4E-10	4.3E-09	0.0007	1.2E-09	0.000003	6.2E-10	4.1E-08
Distance to Receptor/WMU Area	3.0E-09	1.6E-08	0.002	4.2E-09	0.00001	2.2E-09	1.5E-07

Table H2-5b Child of Farmer Individual Risk from Inhalation for Non-utility Coal Co-managed Wastes Managed in Offsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	7.0E-11	3.6E-10	0.00007	9.8E-11	0.0000003	5.2E-11	3.5E-09
Single High-end Parameter							
Long Exposure	1.7E-10	8.9E-10	0.00007	2.4E-10	0.0000003	1.3E-10	8.6E-09
Constituent Conc.	1.8E-10	3.2E-09	0.0008	1.8E-10	0.000001	2.1E-10	1.7E-08
Meteorological Location	6.2E-11	3.2E-10	0.00007	8.6E-11	0.0000003	4.5E-11	3.1E-09
Distance To Receptor	3.6E-10	1.9E-09	0.0004	5.1E-10	0.000002	2.7E-10	1.8E-08
WMU Area	6.8E-10	3.5E-09	0.0007	9.5E-10	0.000003	5.0E-10	3.4E-08
Double High-end Parameters							
Constituent Conc./Long Exposure	4.5E-10	8.0E-09	0.0008	4.5E-10	0.000001	5.1E-10	4.2E-08
Meteorological Location/Long Exposure	1.5E-10	7.9E-10	0.00007	2.1E-10	0.0000003	1.1E-10	7.6E-09
Distance to Receptor/Long Exposure	9.0E-10	4.6E-09	0.0004	1.3E-09	0.000002	6.6E-10	4.5E-08
WMU Area/Long Exposure	1.7E-09	8.7E-09	0.0007	2.3E-09	0.000003	1.2E-09	8.3E-08
Waste Concentration/ Meteorological Location	1.6E-10	2.8E-09	0.0007	1.6E-10	0.0000009	1.8E-10	1.5E-08
Waste Concentration/ Distance to Receptor	9.4E-10	1.7E-08	0.004	9.5E-10	0.000005	1.1E-09	8.8E-08
Waste Concentration/ WMU Area	1.8E-09	3.1E-08	0.008	1.8E-09	0.00001	2.0E-09	1.7E-07
Meteorological Location/Distance to Receptor	3.4E-10	1.7E-09	0.0004	4.7E-10	0.000002	2.5E-10	1.7E-08
Meteorological Location/WMU Area	6.1E-10	3.2E-09	0.0007	8.6E-10	0.000003	4.5E-10	3.0E-08
Distance to Receptor/WMU Area	2.2E-09	1.2E-08	0.002	3.1E-09	0.00001	1.6E-09	1.1E-07

Table H2-5c Adult Resident and Home Gardener Individual Risk from Inhalation for Non-utility Coal Co-managed Wastes Managed in Offsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	3.1E-11	1.6E-10	0.00007	4.4E-11	0.0000003	2.3E-11	1.6E-09
Single High-end Parameter							
Long Exposure	3.1E-10	1.6E-09	0.00007	4.3E-10	0.0000003	2.3E-10	1.5E-08
Constituent Conc.	8.1E-11	1.5E-09	0.0008	8.2E-11	0.000001	9.3E-11	7.6E-09
Meteorological Location	2.8E-11	1.4E-10	0.00007	3.9E-11	0.0000003	2.0E-11	1.4E-09
Distance To Receptor	1.6E-10	8.5E-10	0.0004	2.3E-10	0.000002	1.2E-10	8.1E-09
WMU Area	3.0E-10	1.6E-09	0.0007	4.3E-10	0.000003	2.2E-10	1.5E-08
Double High-end Parameters							
Constituent Conc./Long Exposure	8.0E-10	1.4E-08	0.0008	8.0E-10	0.000001	9.1E-10	7.5E-08
Meteorological Location/Long Exposure	2.7E-10	1.4E-09	0.00007	3.8E-10	0.0000003	2.0E-10	1.3E-08
Distance to Receptor/Long Exposure	1.6E-09	8.3E-09	0.0004	2.2E-09	0.000002	1.2E-09	7.9E-08
WMU Area/Long Exposure	3.0E-09	1.5E-08	0.0007	4.2E-09	0.000003	2.2E-09	1.5E-07
Waste Concentration/ Meteorological Location	7.2E-11	1.3E-09	0.0007	7.2E-11	0.0000009	8.2E-11	6.7E-09
Waste Concentration/ Distance to Receptor	4.2E-10	7.5E-09	0.004	4.3E-10	0.000005	4.8E-10	4.0E-08
Waste Concentration/ WMU Area	7.9E-10	1.4E-08	0.008	8.0E-10	0.00001	9.0E-10	7.4E-08
Meteorological Location/Distance to Receptor	1.5E-10	7.8E-10	0.0004	2.1E-10	0.000002	1.1E-10	7.5E-09
Meteorological Location/WMU Area	2.8E-10	1.4E-09	0.0007	3.9E-10	0.000003	2.0E-10	1.4E-08
Distance to Receptor/WMU Area	1.0E-09	5.2E-09	0.002	1.4E-09	0.00001	7.4E-10	5.0E-08

Table H2-6a Farmer Individual Risk from Inhalation for FBC Wastes Managed in Onsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	5.7E-10	8.6E-09	0.0004	7.1E-10	0.000001	1.9E-10	6.4E-08
Single High-end Parameter							
Long Exposure	2.3E-09	3.5E-08	0.0004	2.8E-09	0.000001	7.6E-10	2.5E-07
Constituent Conc.	2.0E-08	7.0E-08	0.001	3.5E-09	0.000003	1.4E-09	1.0E-07
Meteorological Location	4.7E-10	7.2E-09	0.0003	5.8E-10	0.000001	1.6E-10	5.3E-08
Distance To Receptor	2.2E-09	3.4E-08	0.002	2.8E-09	0.000005	7.5E-10	2.5E-07
WMU Area	1.4E-09	2.1E-08	0.001	1.7E-09	0.000003	4.6E-10	1.5E-07
Double High-end Parameters							
Constituent Conc./Long Exposure	7.8E-08	2.8E-07	0.001	1.4E-08	0.000003	5.5E-09	4.1E-07
Meteorological Location/Long Exposure	1.9E-09	2.9E-08	0.0003	2.3E-09	0.000001	6.3E-10	2.1E-07
Distance to Receptor/Long Exposure	8.9E-09	1.4E-07	0.002	1.1E-08	0.000005	3.0E-09	***1.0E-06***
WMU Area/Long Exposure	5.5E-09	8.3E-08	0.001	6.8E-09	0.000003	1.8E-09	6.1E-07
Waste Concentration/ Meteorological Location	1.6E-08	5.8E-08	0.001	2.9E-09	0.000002	1.1E-09	8.5E-08
Waste Concentration/ Distance to Receptor	7.7E-08	2.8E-07	0.006	1.4E-08	0.00001	5.4E-09	4.1E-07
Waste Concentration/ WMU Area	4.7E-08	1.7E-07	0.004	8.4E-09	0.000007	3.3E-09	2.5E-07
Meteorological Location/Distance to Receptor	2.0E-09	3.0E-08	0.001	2.4E-09	0.000004	6.6E-10	2.2E-07
Meteorological Location/WMU Area	1.2E-09	1.8E-08	0.0008	1.5E-09	0.000002	3.9E-10	1.3E-07
Distance to Receptor/WMU Area	5.0E-09	7.6E-08	0.004	6.2E-09	0.00001	1.7E-09	5.6E-07

Table H2-6b Child of Farmer Individual Risk from Inhalation for FBC Wastes Managed in Onsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	4.2E-10	6.4E-09	0.0004	5.2E-10	0.000001	1.4E-10	4.7E-08
Single High-end Parameter							
Long Exposure	1.0E-09	1.6E-08	0.0004	1.3E-09	0.000001	3.5E-10	1.2E-07
Constituent Conc.	1.4E-08	5.2E-08	0.001	2.6E-09	0.000003	1.0E-09	7.6E-08
Meteorological Location	3.5E-10	5.3E-09	0.0003	4.3E-10	0.000001	1.2E-10	3.9E-08
Distance To Receptor	1.6E-09	2.5E-08	0.002	2.0E-09	0.000005	5.5E-10	1.8E-07
WMU Area	1.0E-09	1.5E-08	0.001	1.2E-09	0.000003	3.4E-10	1.1E-07
Double High-end Parameters							
Constituent Conc./Long Exposure	3.6E-08	1.3E-07	0.001	6.4E-09	0.000003	2.5E-09	1.9E-07
Meteorological Location/Long Exposure	8.5E-10	1.3E-08	0.0003	1.1E-09	0.000001	2.9E-10	9.6E-08
Distance to Receptor/Long Exposure	4.0E-09	6.1E-08	0.002	5.0E-09	0.000005	1.4E-09	4.5E-07
WMU Area/Long Exposure	2.5E-09	3.8E-08	0.001	3.1E-09	0.000003	8.3E-10	2.8E-07
Waste Concentration/ Meteorological Location	1.2E-08	4.3E-08	0.001	2.1E-09	0.000002	8.4E-10	6.3E-08
Waste Concentration/ Distance to Receptor	5.7E-08	2.0E-07	0.006	1.0E-08	0.00001	4.0E-09	3.0E-07
Waste Concentration/ WMU Area	3.5E-08	1.2E-07	0.004	6.2E-09	0.000007	2.5E-09	1.8E-07
Meteorological Location/Distance to Receptor	1.4E-09	2.2E-08	0.001	1.8E-09	0.000004	4.9E-10	1.6E-07
Meteorological Location/WMU Area	8.6E-10	1.3E-08	0.0008	1.1E-09	0.000002	2.9E-10	9.6E-08
Distance to Receptor/WMU Area	3.7E-09	5.6E-08	0.004	4.5E-09	0.00001	1.2E-09	4.1E-07

Table H2-6c Adult Resident and Home Gardener Individual Risk from Inhalation for FBC Wastes Managed in Onsite Landfill

Parameters Set to High-end	Nickel	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium VI
Central Tendency	1.9E-10	2.9E-09	0.0004	2.3E-10	0.000001	6.3E-11	2.1E-08
Single High-end Parameter							
Long Exposure	1.8E-09	2.8E-08	0.0004	2.3E-09	0.000001	6.2E-10	2.1E-07
Constituent Conc.	6.5E-09	2.3E-08	0.001	1.2E-09	0.000003	4.6E-10	3.4E-08
Meteorological Location	1.6E-10	2.4E-09	0.0003	1.9E-10	0.000001	5.2E-11	1.7E-08
Distance To Receptor	7.4E-10	1.1E-08	0.002	9.1E-10	0.000005	2.5E-10	8.3E-08
WMU Area	4.5E-10	6.9E-09	0.001	5.6E-10	0.000003	1.5E-10	5.1E-08
Double High-end Parameters							
Constituent Conc./Long Exposure	6.3E-08	2.3E-07	0.001	1.1E-08	0.000003	4.5E-09	3.3E-07
Meteorological Location/Long Exposure	1.5E-09	2.3E-08	0.0003	1.9E-09	0.000001	5.1E-10	1.7E-07
Distance to Receptor/Long Exposure	7.2E-09	1.1E-07	0.002	8.9E-09	0.000005	2.4E-09	8.1E-07
WMU Area/Long Exposure	4.4E-09	6.7E-08	0.001	5.5E-09	0.000003	1.5E-09	5.0E-07
Waste Concentration/ Meteorological Location	5.3E-09	1.9E-08	0.001	9.6E-10	0.000002	3.8E-10	2.8E-08
Waste Concentration/ Distance to Receptor	2.5E-08	9.1E-08	0.006	4.5E-09	0.00001	1.8E-09	1.3E-07
Waste Concentration/ WMU Area	1.6E-08	5.6E-08	0.004	2.8E-09	0.000007	1.1E-09	8.2E-08
Meteorological Location/Distance to Receptor	6.5E-10	9.9E-09	0.001	8.1E-10	0.000004	2.2E-10	7.3E-08
Meteorological Location/WMU Area	3.9E-10	5.9E-09	0.0008	4.8E-10	0.000002	1.3E-10	4.3E-08
Distance to Receptor/WMU Area	1.6E-09	2.5E-08	0.004	2.0E-09	0.00001	5.5E-10	1.8E-07

Appendix I

Ecotoxicological Profiles for Constituents of Concern

Ecotoxicological Profile for Ecological Receptors
Antimony

This ecotoxicological profile on antimony contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (5) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of antimony so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

Antimony and its compounds are naturally present in the earth's crust. Releases to the environment result from weathering, volcanic exhalations, sea spray, forest fires, and biogenic sources, as well as from anthropogenic activities. Anthropogenic sources include metal smelting and refining, coal-fired power plants, and refuse incineration.

- Antimony is characterized by four oxidation states (-3, 0, +3, and +5).
- In oxidizing environments, $Sb(OH)_6^-$ is the dominant species for pH values greater then 3.
- $Sb(OH)_3$ is the dominant species under relatively reducing conditions.

The speciation and physicochemical state of antimony are important in assessing its behavior in the environment and its availability to biota. Antimony is characterized by four oxidation states (-3, 0, +3, and +5). Trivalent antimony (Sb^{3+}) and Sb^{5+} are the stable oxidation states in aqueous solutions. Most of the Sb^{5+} compounds are soluble (EPRI, 1984).

Antimony forms complex ions with both organic and inorganic acids. One of the best known organic complexes is antimony potassium tartrate ($C_8H_4K_2O_{12}Sb_2 \cdot 3H_2O$). Antimony in the form of Sb^{3+} or Sb^{5+} does not exist in solution, rather it occurs as hydrolyzed forms (e.g., $Sb(OH)_6^-$). The dominant species in the pH range typical of environmental conditions are $Sb(OH)_3$ and $Sb(OH)_6^-$. In oxidizing environments, $Sb(OH)_6^-$ is the dominant species for pH values greater than 3, whereas $Sb(OH)_3$ is the dominant species under relatively reducing conditions. In the presence of sulfur, stable complexes such as $Sb_2S_4^{2-}$ may form.

II. Geochemistry of Antimony in Various Ecological Media

Antimony in Soils

Antimony occurs in soils and rocks in very low concentrations. The typical range in soils is from less then 1 to 8.8 parts per million (ppm), with a mean concentration of 0.48 ppm. This is the third lowest of 50 elements surveyed by the U.S. Geological Survey.

Little is known about the adsorption potential of antimony in soil. Some studies suggest that antimony is fairly mobile under diverse environmental conditions, whereas others suggest that it is strongly adsorbed to soil (ATSDR, 1992). The studies suggesting that antimony is strongly adsorbed to soils, as cited in ATSDR (1992), were conducted using specific antimony species. The resultant conclusions may be species- and system-conditional, and as a consequence, their relevance to natural soil environments is uncertain.

- Antimony is characterized by low concentrations in soils.
- Studies describing adsorption of antimony to soil substrates are contradictory.
- The anionic character of antimony suggests that it would not be highly sorbed under alkaline or oxidizing conditions, and as a consequence, would be more mobile in the environment under these conditions.

Since antimony has an anionic character (e.g., $Sb(OH)_6^-$), it is not expected to have a great affinity for organic carbon or for the negatively-charged substrates typical of alkaline environments. Furthermore, it is not expected that cation exchange, which generally dominates adsorption reactions to clay, would be important for anionic antimony. However, as the pH decreases to weakly acidic conditions, adsorption reactions may increase in importance. Antimony is known to form co-precipitates with hydrous iron, manganese, and aluminum oxides in soils and sediment. These reactions may limit mobility in soil systems.

Antimony in Surface Water

Antimony has a low occurrence in surface waters. In a survey of dissolved antimony in ambient waters, performed by the U.S. Geological Survey, only six percent of the 1,077 survey measurements exceeded the probable detection limit of 5 parts per billion (ppb). It was determined that the population geometric mean and the standard deviation for these samples were 0.25 ppb and 7.16 ppb, respectively. This is consistent with data reported by other researchers for pristine conditions.

- Antimony is characterized by low concentrations in surface waters.
- Antimony is present in the pentavalent oxidation state (Sb^{5+}) in oxidizing waters for the pH range characterizing environmental conditions. The dominant species are reported to be $Sb(OH)_6^-$ and $Sb(OH)_5^0$.
- Trivalent antimony is the dominant oxidation state under anaerobic conditions. Dominant species include $Sb(OH)_3^0$, $Sb(OH)_4^-$, and $Sb_2S_4^{2-}$.

Because the concentration of antimony in natural water systems is so low, there is little available information regarding the speciation and associated behavior of antimony in aqueous environments. Thermodynamically, dissolved antimony in natural waters under aerobic conditions is expected to be present in the +5 oxidation state. At 0.001 M total antimony, the dominant species were reported as $Sb(OH)_6^-$ and $Sb(OH)_5^0$. Polynuclear species ($Sb_{12}(OH)_{64}{}^{4-}$ and $Sb_{12}(OH)_{65}{}^{5-}$ may also be present in very small quantities. As with all polynuclear complexes, the importance of the $Sb_{12}(OH)_x$ species increases as the total antimony concentration increases (EPRI, 1984). Although trivalent antimony species would not be expected to be important under aerobic conditions, low concentrations may be present under aerobic conditions (ATSDR, 1992).

Trivalent antimony is expected to be the dominant oxidation state in anaerobic water. Dominant species include $Sb(OH)_3^0$, $Sb(OH)_4^-$, and $Sb_2S_4^{2-}$. Antimony may be reduced and methylated by microorganisms in anaerobic sediment, releasing volatile methylated antimony compounds into the water.

Antimony in Sediments

- Sediments act as a sink for removal of antimony from the water column.
- Antimony may be re-mobilized from the sediment back into the water column.
- Release of antimony is pH-dependent.
- Antimony will likely be released as the pentavalent oxidation state at environmental pH conditions.
- Antimony may also be re-mobilized into the water column through microbial reduction and methylation.

Few data are available on the concentration of antimony in pristine sediments. Antimony concentrations in sediment collected from non-contaminated areas in Puget Sound in Washington (the site of a copper smelter) ranged from 0.3 to 1.0 part per million (ppm). Because sediments are considered to be a sink for antimony, it is expected that concentrations in sediments would exceed those in surface water.

There is some evidence to suggest that the antimony found in natural water systems is associated with particulate matter (ATSDR, 1992). Antimony is believed to accumulate in sediment as a consequence of the natural settling processes that occur when a surface water body such as a river empties into a lake or bay.

Antimony deposited in sediments can be re-mobilized and released back into the water column. Leaching experiments performed on river sediment samples from a mining district in Idaho found that the form of antimony leached from the sediments was dependent upon pH. At a pH value of 2.7 (which is below the typical pH range for environmental conditions, i.e., 5 - 9), the bulk of the antimony released was in the form of trivalent antimony (Sb^{3+}); at a pH of 4.3, antimony was measured at comparable concentrations of the trivalent and pentavalent species (Sb^{5+}); and at pH values equal to and exceeding 6.3, the pentavalent species was dominant. It is likely that it was present as $Sb(OH)_6^-$ and $Sb(OH)_5^0$. Hence, the pentavalent species of antimony is expected to be dominant in the pH range characterizing environmental conditions. This is consistent with thermodynamic predictions.

Antimony may also be re-mobilized into the water column through microbial reduction and methylation. These reactions are most likely to occur in reducing environments, such as those found in sedimentary deposits. The end result is the release of volatile methylated antimony compounds into the water column.

III. Effects Characterization for Ecological Receptors

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystem

The database on the effects of antimony to aquatic organisms is not extensive but does contain several studies. Studies of acute antimony exposure have yielded species mean acute values for

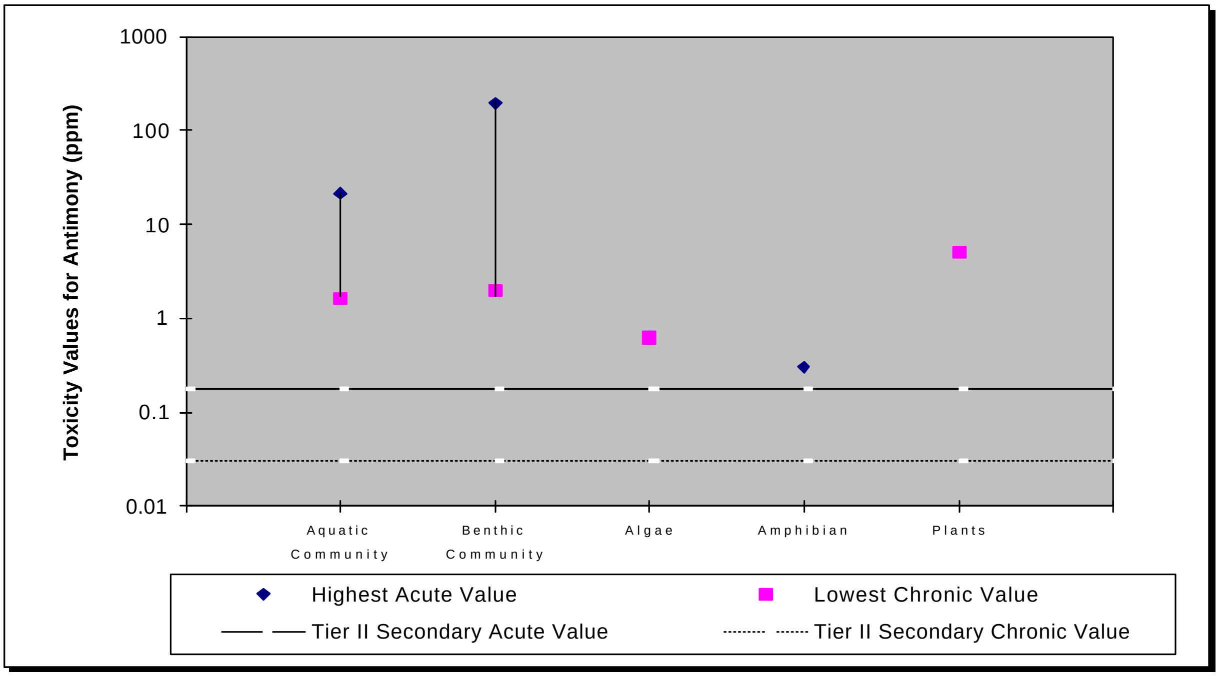

Figure 1: Antimony: Effects Ranges for Ecological Receptors

fathead minnows of 21,900 µg/L and for *Daphnia magna* of 18,800 µg/L. From life cycle studies of *Daphnia magna*, a chronic value of 5,400 µg/L was derived (Sb_2O_3). A chronic, embryo-larval stage study of the fathead minnow produced no effects at the highest test level of 7.5 µg/L, as antimony trioxide. A similar study that tested higher concentrations of antimony trichloride, however, yielded a chronic value of 1,600 µg/L (U.S. EPA, 1980c).

Data suggest that aquatic plants are more sensitive to antimony, at least after acute exposure, than fish or aquatic invertebrates. In algae, a fifty percent inhibition in photosynthesis and growth in *Selenastrum capricornutum* was indicated in the range of 610 µg/L and 630 µg antimony/L, respectively (U.S. EPA, 1980c). Acute effects to amphibians have been indicated at 0.3 mg/L (U.S. EPA, 1996).

Terrestrial Ecosystem

Oral exposures have resulted in systemic and developmental effects. Chronic oral exposure to a low dose of organic potassium antimony tartrate (5 ppm) shortened rat life spans (Schroeder et al., 1970). Chronic exposures have also had vasomotor, hematological, and hepatic effects in rats and guinea pigs (Marmo et al., 1987; ATSDR, 1992). Acute oral exposures have resulted in vomiting, diarrhea, kidney effects, and death. Dermal exposure has caused eye and skin irritation and some possible neurological effects (ATSDR, 1992). For plants, Kabata-Pendias and Pendias (1992) have phytotoxic effects observed at 5 and 10 mg/kg soil, but the type of plant and toxicity effects are not specified. No other studies have been identified on plants and soil invertebrates.

IV. Bioaccumulation Potential

Freshwater Ecosystem
Sufficient data to determine bioconcentration factor (BCF) values for algae and aquatic invertebrates were not identified. For fish, BCF of 0 (L water/kg tissue) was used. This is based on whole-body measured BCFs of bluegill sunfish (*Lepomis macrochirus*) with 28 days of exposure (Sb_2O_3; Sb^{3+}) (Barrows et al., 1980). As cited by both Stephan (1993) and Barrows et al. (1980), concentration of antimony in bluegill sunfish did not exhibit significant increase above that of the control. It is assumed that the bioconcentration of antimony is negligible. Although the authors believed to antimony concentration have reached a steady-state, no other study on bioaccumulation was identified. Additional data identified in the future may provide further update.

Terrestrial Ecosystem
Sufficient data were not identified to determine bioconcentration factors (BCFs) for terrestrial vertebrates or terrestrial invertebrates, plants, and earthworms.

V. CSCL Development

The benchmark values presented in this section for mammals and birds were used to derive protective media-specific CSCLs as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor and the potential bioconcentration in prey, a protective concentration (i.e., CSCLs) in soil, plants or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. It is assumed that by protecting the more sensitive species, the other receptors are protected as well.

Mammals:
Rossi et al. (1987) exposed female rats to 1.0 and 10 mg/L antimony trichloride in drinking water from the first day of pregnancy until weaning, 22 days after delivery. Pups were then exposed to the same doses from weaning until age 60 days. No teratogenic effects were observed, but body weights were reduced both in mothers exposed to 10 mg/L antimony trichloride and in their pups. This resulted in a NOAEL of 1.0 mg/L. Based on the average of the reported body weights for parent rats (0.255 kg), and a daily water consumption of 0.036 L/day estimated with the allometric equation presented above (U.S. EPA, 1988a), the 1.0 mg/L dose of antimony trichloride was converted to a daily dose of 0.14 mg/kg-day (antimony trichloride).

The NOAEL in the Rossi et al. (1987) study was selected to derive the toxicological benchmark because: (1) doses were administered over a chronic duration and via oral ingestion, an ecologically significant exposure pathway; (2) the study focused on developmental toxicity as a critical endpoint; and (3) it contained adequate dose-response information.

Schroeder et al. (1970) exposed Long-Evans rats to 5 ppm antimony as potassium antimony tartrate in drinking water from weaning until natural death. A decrease in the median life span was observed as well as abnormal serum glucose levels, suggesting a LOAEL for survival effects of 5 ppm. Conversion of this value to a daily dose in units of mg/kg-day required the use of an allometric equation for daily water consumption for laboratory mammals (U.S. EPA, 1988a):

$$\textit{Water Consumption} = 0.10W^{0.7377}$$

where W is body weight in kilograms. Using the geometric mean of the reported male and female body weights (0.238 kg), a calculated water consumption rate of 0.035 L/day, the ppm dose was converted to a daily dose of 0.74 mg/kg-day. In another study by Schroeder et al. (1968a), the effects of 5 ppm of antimony potassium tartrate in drinking water were observed in Charles River CD mice, dosed from weaning until natural death. A decrease in the median life span of females and growth suppression in animals at 18 months of age was observed at this dose, suggesting a LOAEL for survival and growth effects of 5 ppm. Conversion of this value to a daily dose in units of mg/kg-day required the use of the allometric equation for daily water consumption for laboratory mammals presented above (U.S. EPA, 1988a). Using the geometric mean of the reported female body weights (0.037 kg), a calculated water consumption rate of 0.0088 L/day, the ppm dose was converted to a daily dose of 1.19 mg/kg-day. The studies by Schroeder et al. (1968a) and (1970) were not selected for the derivation of a benchmark because they did not evaluate reproductive or developmental endpoints, and only a single dose level were tested.

Birds: No subchronic or chronic studies were identified which studied the toxicity effects of orally ingested antimony in avian species.

Freshwater Community: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria (NAWQC) published by the EPA Office of Water. The draft FCV of 3.0E-02 mg/L for antimony and developed under the NAWQC was selected as the appropriate criteria to use in this analysis because no criteria were available for antimony under GLWQI work (U.S. EPA, 1988). The GLWQI value was considered preferable to the NAWQC because: (1) the GLWQI value is based on the same methodology used to develop NAWQC (i.e., Stephan et al., 1985); (2) the NAWQC data set was augmented with previously unavailable acute and chronic toxicity data; and (3) species taxa used to generate the GLWQI values are suitable for national application since they include species and taxa found throughout the United States. But lacking the GLWQI value for antimony, the draft NAWQC was used.

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metals concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). EPA has developed conversion factors (CFs) to estimate probable dissolved concentrations of metals in surface waters given a total metal concentration as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). A CF is not yet available for antimony. This adjustment reflects the current Agency position on criteria development and regulatory application of metals; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). The final surface water CSCL for antimony is presented in Table 1.

Amphibians: No suitable subchronic or chronic studies were identified which studied the effects of antimony toxicity on reproductive or developmental endpoints in amphibian species. Only one study indicating acute effects was identified. Acute seven day exposures of antimony to

Gastrophryne carolinensis embryos indicated 50 percent mortality at 0.3 mg antimony/L. This value was used to develop the acute amphibian CSCL; however, low confidence is assigned to this CSCL because it does not adequately present variability that could be introduced by using other species, life stages, and exposure durations (Power et al., 1989; U.S. EPA, 1996).

<u>Algae and Aquatic Plants:</u> Relevant endpoints for aquatic plants focused on the ability of plants to support higher trophic levels as well as the ability to provide habitat for other species in the freshwater ecosystem. The benchmarks for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or (2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). The aquatic plant CSCL for antimony is 0.61 mg/L based on a 4-day EC_{50} for chlorophyll A inhibition in *Selenastrum capricornutum* (Suter and Tsao, 1996).

<u>Benthic Community</u>- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, criteria are developed estimating the 10th percentile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long and Morgan, 1991). From the values generated, the ER-L was selected as the sediment CSCL. These values are not NOAA standards; rather, they are used to rank sites based on the potential for adverse ecological effects. A second criteria document evaluated for sediment criteria development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the criteria was changed. FDEP calculated the criteria (i.e., threshold effects level, TEL) from the geometric mean of the 50^{th} percentile of no effects data and the 15^{th} percentile of the low effects data. The NOAA data, used in both documents, is based on total metal concentrations in sediments, and the toxicity endpoints were measured on species of amphipods, arthropods, and bivalves in addition to a variety of community-based endpoints (e.g., abundance, mortality, species composition, species richness). The FDEP did not evaluate antimony in sediments; hence, the NOAA sediment criteria was selected.

The CSCL for antimony was derived from 13 toxicity data points for primarily low effects levels. For the screening level analysis of antimony, the ER-L of 2.0E+00 mg antimony/kg sediment was selected as an appropriate sediment CSCL. Based on the quality and quantity of antimony sediment data, the degree of confidence in the ER-L value for antimony was considered low (Long and Morgan, 1991). The low confidence was generated by the lack of data and the uncertainty around proposing an ER-L for marine biota and applying it to freshwater systems.

<u>Terrestrial Plants</u>: As presented in Efroymson et al. (1997a), phytotoxicity benchmarks were selected by rank ordering the lowest observable effects concentration (LOEC) values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the benchmark. Such LOECs applied to reductions in plant growth, yield, or seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. The proposed CSCL for phytotoxic effects of antimony in soils is 5 mg antimony/kg

soil, based on unspecified toxic effects on plants grown in soil containing 5 ppm antimony (Efroymson et al., 1997a). Since the CSCL was based on a single study reporting unspecified effects and did not indicate the form of antimony applied to test soils or the terrestrial plant species exposed, this benchmark study was not appropriate for CSCL development. No further studies were identified, so no CSCLs could be developed for the terrestrial plant community.

Soil Community: No appropriate studies have been identified to derive a soil CSCLs for antimony.

Table 1. Antimony CSCLs in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Mammals	7.0E-01	mg/L water	Food web	River Otter	Rossi et al., 1987
Algae and Aquatic Plants	6.1E-01	mg/L water	Direct contact	*Selenastrum capricornutum*	Suter and Tsao, 1996
Freshwater Community Total	3.0E-02	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1988
Benthic Community	2.0E+00	mg/kg sediment	Direct contact	Benthos	Long et al., 1991
Amphibians (acute effects)	3.0E-01	mg/L water	Direct contact	*Gastrophryne carolinensis*	Power et al., 1989; U.S. EPA, 1996
Terrestrial					
Mammals	1.4E+01	mg/kg soil	Food web	Raccoon	Rossi et al., 1987
Mammals	7.2E-01	mg/kg plant tissue	Food web	Meadow vole	Rossi et al., 1987

Insufficient data for birds and soil community

Ecotoxicological Profile for Ecological Receptors
Arsenic

This ecotoxicological profile on arsenic contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (3) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of arsenic so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

- ! Arsenic is ubiquitous in the environment.
- ! Arsenic exists in nature in the -3, 0, +3, and +5 valence states. However, in aqueous solutions, the +3 and +5 are the most important.
- ! Theoretically, As^{5+} should dominate As^{3+} at the redox potentials typical of aerobic environments. However, thermodynamically predicted.
- ! As^{5+}/As^{3+} ratios are rarely observed;
- ! Biologically mediated reactions are important in influencing the behavior of arsenic in the environment.
- ! The whole biogeochemical cycle of arsenic can only be understood properly in terms of the dynamic balance of the environmental processes of different arsenic species.

Arsenic (As) is a ubiquitous element which occurs in the atmosphere, in the aquatic environment, in soils and sediments, and in organisms. Arsenic exists in nature in the -3, 0, +3, and +5 valence states. However, in aqueous solutions, the +3 and +5 valences are the most important.

Natural and anthropogenic inputs vary geographically, and different environments show a wide range of concentrations. Determining typical arsenic values is quite difficult, and often only a general range of levels (ppm, ppb, ppt) can be established. Despite these limitations, the environmental behavior of arsenic is clearly dependent on the physical and chemical properties, toxicity, mobility, and biotransformation of individual arsenic compounds. The arsenic biogeochemical cycle can only be properly understood in terms of the dynamic balance of biological, chemical, physical, and geological processes of individual arsenic species (Cullen and Reimer, 1989).

The biological availability and physiological and toxicological effects of arsenic depend on its chemical form. $Arsenic^{3+}$ is much more toxic, more soluble, and more mobile than As^{5+}. Cullen and Reimer (1989) presented a review of the predicted environmental speciation of arsenic. At redox potentials typical of aerobic soils and oxygenated aquatic systems, As^{5+} should dominate As^{3+}. Thermodynamically predicted As^{5+}/As^{3+} ratios are rarely observed, and experimental evidence indicates that many factors influence the relative concentrations of these species. Biologically mediated redox reactions are the most important of these factors. Crecelius et al. (1986) suggested that a thermodynamic equilibrium between the As^{3+} and As^{5+} oxidation states does not exist for natural waters; instead a steady state may be achieved. Organoarsenic compounds are widely distributed in the environment. A review by Craig (1985) of environmental organometallic compounds notes that the methylated form predominates. For arsenic, the synthesis of organoarsenic compounds requires a living organism to be involved and organoarsenicals originate through biomethylation.

Dissolved arsenic can occur in natural waters in both inorganic and organic forms. The inorganic forms include formal oxidation states As^{5+}, arsenate, and As^{3+}, arsenite, with the primary aqueous species at natural pHs being anionic in arsenate ($H_2AsO_4^-$ and $HAsO_4^{2-}$) or neutral for arsenite ($As(OH)_3^0$) (Anderson and Bruland, 1991). The location of arsenic on the periodic table directly below phosphorus predicts analogous chemical behavior for arsenate and phosphate including incorporation into organic molecules (Anderson and Bruland, 1991).

The speciation of arsenic in natural waters is influenced by a number of biogeochemical processes. In oxygenated waters, the oxidation state +5 (arsenate) is thermodynamically stable, but both bacteria and planktonic algae can reduce As^{5+} to the +3 oxidation state (arsenite) even in the presence of dissolved oxygen (Andreae and Andreae, 1989 and references therein). This results in the presence of As^{3+} at relatively low levels (usually <10%) in most natural waters. In addition, algae take up As^{5+} from their environment and excrete a variable fraction of this arsenic in the form of the methylated species, monomethylarsonic acid (MMAA), and dimethylarsinic acid, DMAA (Andreae, 1986).

II. Geochemistry of Arsenic in Various Ecological Media

Arsenic in Soils

There is a wide range of concentrations of arsenic in soils. Yang-Chu (1994) reports arsenic concentrations ranging from approximately 1 to 600 ppm for soils from around the world. Bhumbla and Keefer (1994) quote typical arsenic concentrations in natural uncontaminated European soils of 5 to 11 ppm, but ranges of 21 to 231 ppm for Chilean soils. Arsenic levels in soils derived from different rock types can also show a wide range in arsenic concentrations (e.g., soils from shales and granites up to 250 ppm, quartzites 100-200 ppm (Bhumbla and Keefer, 1994)).

- ! Arsenic concentrations in soils are in the range one up to a few hundred ppm.
- ! Inorganic arsenate and arsenite are the main forms of arsenic in soils. Both forms are subject to chemically and biologically mediated redox and methylation reactions.
- ! Adsorption, dissolution, precipitation, and volatilization reactions are common.

Arsenic occurs mainly in inorganic species but can also be bound to organic material in soils. Inorganic species may be transformed to organoarsenic compounds by soil micro-organisms. The forms of arsenic present depend on factors including the type and amount of sorbing compounds of the soil, pH, and redox potential.

Arsenate, As^{5+}, and arsenite, As^{3+}, are the primary arsenic forms in soils. Both As^{5+} and As^{3+} are subject to chemically and/or microbially mediated oxidation-reduction and methylation reactions in soils. In addition, adsorption, dissolution, precipitation, and volatilization reactions commonly occur. The volatile organic arsines are extremely toxic.

A number of studies have dealt with arsenic sorption on specific minerals and soils. Amorphous iron and aluminum hydroxides (Pierce and Moore, 1982; Sakata, 1987), clay content (arsenate can be sorbed onto clays, especially kaolinite and montmorillonite) (Frost and Griffen, 1977; Elkhatib et al., 1984), redox potential, and pH (Pierce and Moore, 1980, 1982; Sakata, 1987; Elkhatib et al., 1984) are particularly important for arsenic sorption. Methylated arsenic oxyacids can be produced by a variety of microorganisms, and their presence has been reported in a wide range of soils and sediments (Masscheleyn et al., 1991).

Masscheleyn et al. (1991) determined that the solubility and speciation of arsenic in soils is governed mainly by redox potential and pH . From their experiments, these workers concluded that qualitatively, arsenic speciation changes according to thermodynamic predictions. Under oxidizing conditions, As^{5+} is the predominant species (65-98%) and arsenic solubility is low. At high pH (alkaline conditions) or under reducing conditions As^{5+} is reduced to As^{3+} which mobilizes arsenic. Under moderately reducing conditions (0-100 mV), arsenic solubility is controlled by the dissolution of iron oxyhydroxides. Arsenic is coprecipitated (as As^{5+}) with the oxyhydroxides and released upon solubilization. The slow kinetics of the As^{5+} - As^{3+} transformation means that a considerable amount of thermodynamically unstable As^{5+} species is observed under reducing conditions. This slow transformation rate and the release of high concentrations of manganese (Mn) upon reduction make the precipitation of a Mn-As phase possible.

Arsenic in Surface Waters

The concentration of arsenic in fresh water exhibits considerable variation with both the geology of the drainage area and the extent of anthropogenic input. Dissolved arsenic concentrations in some European and North and South American rivers show a geometric mean concentration of 1.4 ppb, with a large range, approximately 0.1 to 75 ppb (Andreae et al., 1983; Andreae and Froelich, 1984). Geothermal waters have high levels of dissolved arsenic (e.g. 1275 ppb in Old Faithful, Yellowstone National Park) (Stauffer and Thompson, 1984), but freshwater lakes can also reach these values. A survey of total arsenic concentrations in rivers and lakes, mostly in California, showed a very wide range of concentrations (lakes, 6.9-230,000 nM; rivers, 8.9-99 nM) (Anderson and Bruland, 1991).

- Surface water arsenic concentrations are typically in the ppb range of levels (<1 to 100 ppb).
- In surface waters, arsenic is present primarily as arsenate. Arsenite and organo-arsenic species (mainly MMAA and DMAA) can also exist;
- The association of arsenic with SPM and sediments is an important factor influencing the biogeochemistry of arsenic.
- Biomethylation can also be an important factor influencing the behavior of arsenic in fresh water environments.

Arsenic in surface waters is present primarily as an inorganic ion, arsenate. In addition, arsenite and methyl arsenicals, monomethylarsonic acid (MMAA) and dimethylarsinic acid (DMAA), may be present (Sanders, 1985; Anderson and Bruland, 1991).

Chunguo and Zihui (1988) showed that As^{5+} was the predominant species in the water of the Xiangjiang River (China). The main species in the sediments of the river were aluminum arsenate, iron arsenate, and calcium arsenate. Lesser species were soluble inorganic arsenic, organic arsenic, and iron-occluded arsenic. Arsenic is mainly transported by suspended solids, and arsenic in suspended solids and sediments was ~2000 times that in river water. Arsenic species are combined with iron, manganese, and aluminum compounds (Sakata, 1987; Brannon and Patrick, 1987; Mok and Wai, 1989, 1990). Sorption of arsenic species by organic matter and humic acids is also possible.

Mok and Wai (1990) determined the distribution and speciation of inorganic arsenic in the Coeur d'Alene River system (Idaho). $Arsenic^{5+}$ was the predominant species in an uncontaminated part of the river system, whereas As^{3+} dominated sections of the river contaminated with mining wastes. Sediments from uncontaminated sections of the river had low arsenic concentrations (~10 ppm) compared with sediments from contaminated areas (~100-200 ppm). In addition, Mok and Wai determined that interaction between water and contaminated sediments was likely to be a major factor controlling the distribution of arsenic species within the system.

Mok and Wai (1994) reviewed the role of sediments in controlling arsenic distribution in freshwater. In a river, arsenic is bound predominantly to sediments. Arsenic in sediments is derived mainly from solids suspended in the overlying water. Consequently, the mobilization of arsenic is closely related to its interaction with sediments. Adsorption, desorption, redox potential, and biological transformations influence arsenic mobility during sediment-water interactions and are partly responsible for controlling arsenic concentrations in river waters. Arsenic is deposited on sediments mainly as manganese and iron hydroxides. The arsenate-arsenite profile with depth in porewaters is governed by the redox profile and by the presence of sulfide. Arsenate and arsenite differ in adsorption characteristics. $Arsenic^{5+}$ is less mobile than As^{3+} because the As^{5+} is adsorbed to a greater extent than the As^{3+} (Pierce and Moore, 1982). $Arsenic^{5+}$ is also coprecipitated with hydroxides.

All the lakes sampled by Anderson and Bruland (1991) had measurable concentrations of methylated arsenic (equivalent to 1 to 59% total As), with the exception of one highly alkaline lake. The four rivers they studied had non-detectable concentrations of DMAA and MMAA. Neither depleted phosphate concentrations nor high dissolved salts correlated with the appearance of methylated forms of arsenic. Anderson and Bruland (1991) also conducted a temporal study of arsenic speciation in Davis Creek Reservoir, a seasonally anoxic lake in northern California, and demonstrated that DMAA increased sufficiently to become the dominant form of dissolved arsenic within the surface photic zone during late summer and fall. MMAA maintained relatively uniform concentrations throughout the water column and throughout the study period. In contrast, DMAA concentrations increased greater than three-fold in the epilimnion during the summer, but had much lower concentrations at depth. Methylated forms decreased while arsenate increased when the lake overturned in early December, implying a degradation of DMAA to arsenate.

Arsenic in Sediments

- Arsenic concentrations in sediments are in the ppm range, and can be of the order of a few hundred ppm.
- Arsenic in sediments derives mainly from SPM settling from the overlying water column.
- The speciation and mobility of arsenic in sediments is controlled by the sediment biogeochemistry (pH, Eh, interstitial pore water chemistry etc.).
- In particular, the concentration of iron, manganese, and aluminum oxide/hydroxide phases influences the retention/release of arsenic from sediments.
- Arsenite is the predominant form of arsenic in anaerobic sediments.

Sediments contain much higher levels of arsenic (ppm) than the overlying fresh or saline waters (ppb). Arsenic concentrations in sediments can be substantial, 100-300 ppm, (Brannon and Patrick, 1987). However, the environmental conditions of the sediments are more important in controlling arsenic speciation and mobility than are the total concentrations of arsenic in the sediment (Brannon and Patrick, 1987). Arsenic retention and release by sediments depends on the chemical properties of the sediments, especially on the concentration of iron, manganese, and aluminum oxides and hydroxides they contain (e.g., Anderson et al., 1976; Pierce and Moore, 1980; Mok and Wai, 1990). However, the mechanism for retention, either adsorption or coprecipitation, is not known. The consistent appearance of arsenic in the manganese-iron oxide fraction of sediments prompted the suggestion that coprecipitation with these oxides may play a role in controlling dissolved arsenic concentrations in the overlying water column (Cullen and Reimer, 1989). An alternative explanation for the association of arsenic with Mn-Fe oxides is preferential post-depositional adsorption of arsenic to this phase. Coprecipitation can be particularly important in estuaries (Cullen and Reimer, 1989). In addition, arsenic-humic acid interactions have been demonstrated and at certain pH values may be more important than adsorption to hydrous oxides (Waslenchuk and Windom, 1978).

Remobilization and desorption of arsenic from sediments is controlled by pH, Eh, and arsenic concentrations in interstitial waters, in addition to changes in total iron, extractable iron, extractable manganese, mineral oxides and hydroxides, and the calcium carbonate equivalent in sediments (Xu et al., 1988; Mok and Wai, 1989, 1990; Brannon and Patrick, 1987; Masscheleyn et al., 1991).

In anaerobic sediments, As^{3+} is generally the predominant form of arsenic. The addition of As^{5+} to a wide variety of anaerobic sediments results in the accumulation of As^{3+} and organic As in the sediment interstitial water and exchangeable phases (Brannon and Patrick, 1987).

Arsenic release to the environment can be enhanced by subjecting river or lake sediments to oxidation, for example by draining reservoirs (Moore et al., 1988). Arsenic coprecipitates with Fe, Mn, or Al oxides. These phases change from mostly oxyhydroxide and organic phases to a sulfide phase in the reducing environment in the sediments. Subsequent exposure of the sediments to oxygen allows bacterially mediated oxygenation of the sulfides releasing iron and any associated arsenic (Moore et al., 1988).

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystems
Arsenic's toxic effects range from relatively minor ones, such as short-term, reversible behavioral impairments and metabolic deficiencies, to more serious ones, such as developmental malformation of offspring and elevated mortality rates. Adverse effects have been noted at aqueous arsenic concentrations of 19 to 48 µg/L and dietary concentrations above 120 mg/kg body weight. In aquatic invertebrates 50% reproductive impairment of *Daphnia magna* was reported following 3 weeks of exposure to 1.4 mg/L (Na_2HAsO_4; As^{5+}), with 50% mortality occurring at 2.9 mg/L (Biesinger and Christensen, 1972). Acute toxicity of *Daphnia pulex* resulting in immobilization was reported at 50 mg/L for arsenic (Na_2HAsO_4; As^{5+}) (Passino and Novak, 1984). Amphibian species demonstrate acute effects (LC_{50}) in the range of 0.04 to 55.4 mg/L (Power et al., 1989; U.S. EPA, 1996). Toxic effects have been observed in avian species as well. Mallards exposed to dietary sodium arsenate (Na_2HAsO_4; As^{5+}) up to 400 µg/g in feed exhibited arsenic accumulation in the liver, delayed egg laying, decreased whole egg weight, and eggshell thinning (Stanley et al., 1994). No effects on hatching success or evidence of teratogenicity were noted. Hatchlings fed the same diet demonstrated a decrease in body and liver weight. It is interesting to note that adverse effects may have been attributable to malnutrition resulting from avoidance of contaminated food, rather than toxicity.

Terrestrial Ecosystems
Because the detoxification and excretion of arsenic is fairly rapid, chronic effects resulting from repeated low-level exposures are not expected. Acute arsenic toxicity in terrestrial vertebrates usually results in rapid (within 2-3 days) mortality or morbidity, although overall sensitivity is reported to decrease with increasing age of the organism exposed. Pathological effects may include pulmonary edema, kidney and liver damage, dehydration, nervous system disturbances, and cardiac abnormalities. Arsenic may cross placental membrane barriers and is a known teratogen in many vertebrates (Eisler, 1988). Ingested arsenic has been reported to be fetotoxic and mildly teratogenic in laboratory animals (ATSDR, 1989; Baxley et al. 1981; Hood and Bishop, 1972; Ferm and Carpenter, 1968). Although many studies indicate arsenic's carcinogenicity in humans, there is little evidence of its carcinogenic effects in animals.

Decreased survival rates in small mammals (mice, rats) are reported for oral doses of arsenic ranging from 0.4 mg/kg-day to over 4.73 mg/kg-day. In birds, the toxic effects induced by arsenic exposure include lack of muscular control, debility, fluffed feathers (Eisler, 1988). Mechanisms mediating arsenic toxicity; however, may vary significantly among species, and thus similar exposure routes may not result in similar effects. For example, rats exhibit a seemingly unique tendency to bind arsenic to hemoglobin in red blood cells (ATSDR, 1989a).

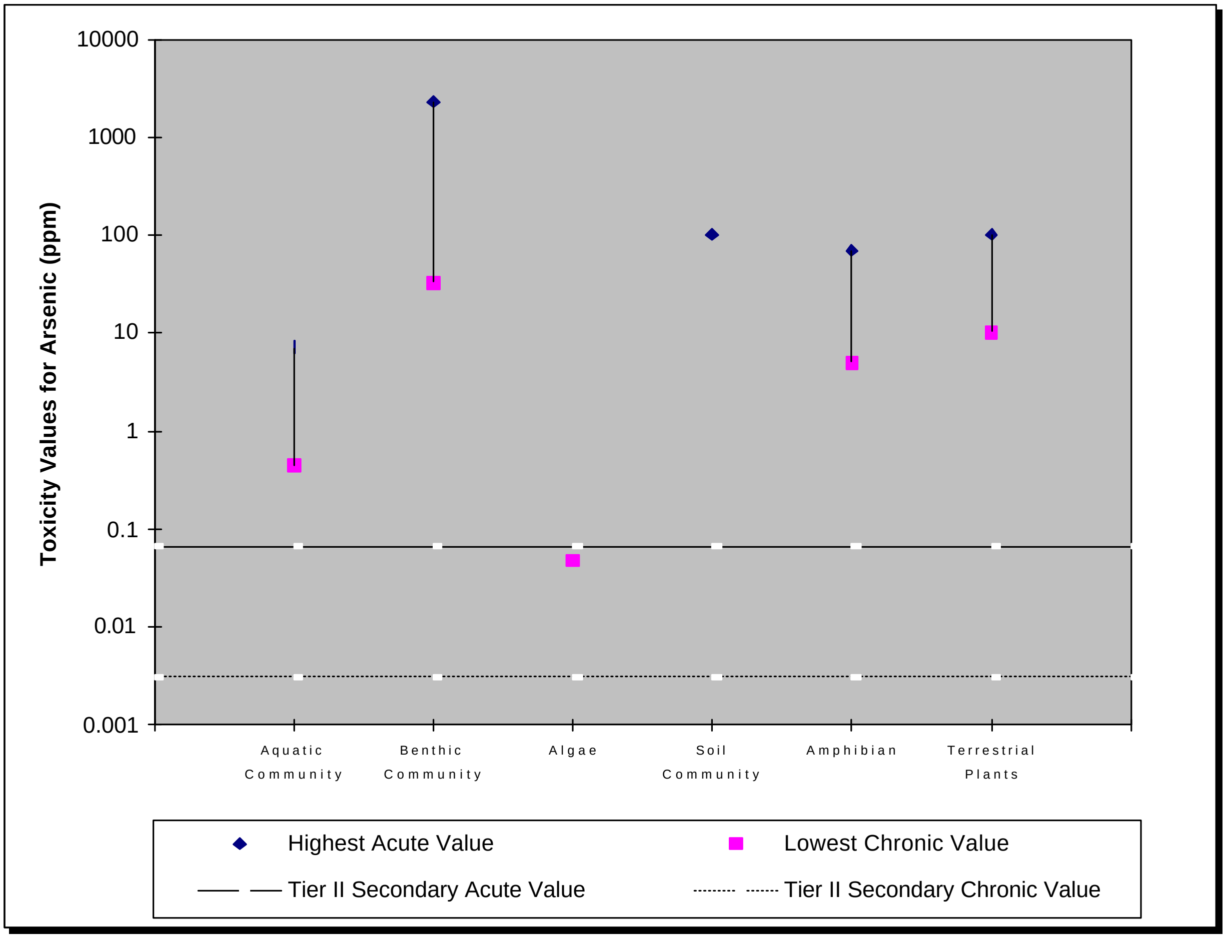

Figure 2: Arsenic: Effects Ranges for Ecological Receptors

In terrestrial animals, the relative efficiencies of assimilation of arsenic via ingestion, absorption, or inhalation are unclear. Available evidence suggests that each may serve as an efficient and relevant route of exposure (ATSDR, 1989a; Baxley et al., 1981). As described for aquatic ecosystems, exposures via oral, dermal, or inhalation pathways of inorganic arsenic will likely be the most significant sources of toxicity. These exposure pathways are expected to be more significant contributors to total arsenic body burdens than food-chain based exposures, as the biomagnification of arsenic by terrestrial biota appears to be insignificant.

Information regarding toxic effects in soil biota are limited. Available evidence suggests that soil microorganisms are fairly tolerant and may be exposed to arsenic concentrations as high as 1600 mg/kg soil without adverse effect (Eisler, 1988). In plants, arsenic is non-essential and toxic exposures may result in the wilting of new leaves, retarded root and stalk growth, and leaf necrosis (Efroymson et al., 1997a, 1994).

IV. Bioaccumulation Potential

Freshwater Ecosystems
Aside from the general rule that inorganic arsenic compounds are more toxic than organic, not much is known about the relative toxicities of different arsenic forms to aquatic organisms or their

relative tendencies for bioaccumulation. Fish have high acute tolerances for arsenic (As^{3+} and As^{5+}) (Spehar et al., 1980) and may accumulate levels of organic arsenic ranging from 4 to 5 ppm to as high as 170 ppm without major impairment (chemical form unspecified) (ATSDR, 1989). Food-chain pathways do not contribute significantly to total arsenic body burdens. A study examining bioaccumulation and toxicity in multiple aquatic trophic levels noted significant bioaccumulation of arsenic in stoneflies, daphnids, and snails, but no appreciable accumulation in higher trophic level organisms (e.g. rainbow trout) after 28 days of aqueous exposure to inorganic arsenic. Arsenic accumulates mostly at lower trophic levels (e.g. aquatic invertebrates), and body burdens may exceed ambient water concentrations by as much as 131 times (chemical form unknown) (Spehar et al., 1980); however, bioconcentration factors for fish are usually quite low. Bioconcentration factors (BCFs) of 3 and 4 from Stephan (1993) in the form of As_2O_3 (As^{3+}) were used to arrive at a geometric mean of 3.46 (L/kg). These are whole-body measured BCFs of bluegills and fathead minnows. Confidence in this value is moderate because of the limited number of studies used to derived the value.

Terrestrial Ecosystems
Bioaccumulation in terrestrial invertebrates, plants, and small mammals is currently being investigated at Oak Ridge National Labs. Bioaccumulation and bioconcentration factors (BAFs and BCFs) for terrestrial plants, invertebrates, and small mammals have been proposed from review of primary literature sources. The 90th percentile of the bioaccumulation data for these receptors derived from both laboratory and field studies were used to determine terrestrial food chain exposures. For earthworms, a BAF of 0.52 was proposed for arsenic based on 53 data points. For terrestrial plants, an BCF of 1.2 was proposed based on 110 data points. For small mammals, based on 72 reported values assessing the transfer of arsenic from soil to small mammals, a BAF of 0.015 was proposed (Sample et al., 1997; Samples et al., 1998). These values were used to model food chain exposures to terrestrial species for this analysis, because currently, they stand as the most comprehensive collection of bioaccumulation data for terrestrial ecological receptors (Sample et al., 1997; 1998a; 1998b).

V. CSCL Development

The benchmark values presented in this section for mammals and birds (e.g., daily dose values) were used to derive protective media-specific CSCL as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor and the potential bioconcentration in prey, a protective concentration (i.e., CSCL) in soil, plants, or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. By protecting the more sensitive species, other receptors are likely to be protected as well.

Mammals: Although As^{3+} has been observed as being more toxic to mammalian species than As^{5+} (Eisler, 1988), toxicological benchmarks were based on studies focusing on As^{5+} when data were available since this form is the most prevalent chemical species in ecological systems. Two studies were identified that investigated the effects of chronic oral exposure to As^{5+} in mammals.

In a two-year study, Byron et al. (1967) fed arsenic as sodium arsenate to rats in doses ranging from 31.25 to 400 ppm. Rats in the group receiving 62.5 ppm did not differ from the controls; however, those in 125 ppm exhibited increased weight loss. Based on these results, a NOAEL of 62.5 ppm and a LOAEL of 125 ppm were inferred for growth effects. Since no information was provided on daily food consumption, conversion from ppm (mg/kg-diet) to mg/kg-day required the use of an allometric equation for laboratory mammals (U.S. EPA, 1988a):

Food Consumption (kg/day) = $0.056(W^{0.6611})$

where W is body weight in kilograms. Using the geometric mean of the reported mean male and female body weights of the control rats (0.439 kg), and a calculated food consumption rate of 0.032 kg/day, the NOAEL of 62.5 ppm was converted to 4.6 mg/kg-day, and the LOAEL of 125 ppm was converted to 9.3 mg/kg-day.

The study by Byron et al. (1967) was considered the most suitable for derivation of a mammalian toxicological benchmark because: (1) it established a dose-response relationship; (2) it focused on growth effects during a critical life stage; and (3) it administered doses via oral ingestion, an ecologically significant exposure pathway. The rat study focused on growth effects during a critical life stage, an endpoint likely to impact the fecundity of a population. Therefore, the NOAEL of 4.6 mg/kg-day from the rat study was chosen for calculation of the mammalian benchmark values.

In a separate experiment the same authors (Byron et al., 1967) fed arsenic as sodium arsenate to dogs for two years at doses of 5, 25, 50 and 125 ppm. Dogs fed doses of 50 ppm or less showed no signs of clinical or pathological toxicity, however, those given 125 ppm exhibited reduced survival and increased weight loss. These results suggest a NOAEL of 50 ppm and a LOAEL of 125 ppm for pathological effects. Conversion from the ppm dose to an equivalent dose in mg/kg-day was done using the allometric equation for laboratory mammals (U.S. EPA, 1988a) presented above. Using an average body weight of 9 kg (U.S. EPA, 1988a) and a calculated food consumption rate of 0.239 kg/day, the NOAEL of 50 ppm was converted to 1.3 mg/kg-day, and the LOAEL of 125 ppm was converted to 3.3 mg/kg-day. This study was based on pathological effects that could not be directly linked to population level effects. The benchmark study using rats (Byron et al., 1967) was selected over the toxicity study using dogs for this reason.

Birds: Two studies that investigated As^{5+} toxicity in avian wildlife were identified. In a two-part study, Stanley et al. (1994) examined arsenic's effect on the reproduction and development of mallard ducks by feeding adult mallards 25, 100 and 400 µg As/g feed for 4 weeks prior to mating. While no signs of toxicity were observed in the two lower dose groups, ducks treated with 400 µg/g exhibited delayed egg laying and lowered duckling production. In addition, the eggs of the 400 µg/g group weighed less than the eggs of the control group and showed signs of eggshell thinning. Based on these results, a NOAEL of 100 mg/kg and a LOAEL of 400 mg/kg can be inferred for reproductive effects. Since no information on body weight or food intake was provided, conversion of the dietary doses from µg/g-diet to mg/kg-day required the use of an allometric equation for birds (Nagy, 1987):

Food consumption (g/day) = $0.648(W^{0.651})$

where W is body weight in grams. Assuming an average weight of 1043 g (U.S. EPA, 1993h) and using the calculated food consumption rate of 60 g/day, the NOAEL of 100 µg/g was converted to

5.7E-03 mg/kg-day and the LOAEL of 400 mg/kg was converted to 2.3E-02 mg/kg-day. The NOAEL of 5.7E-03 mg/kg-day inferred from the Stanley et al. (1994) adult mallard study was selected. The NOAEL of 5.7E-03 mg/kg-day was then scaled using the cross-species scaling algorithm adapted from Opresko et al. (1994). Although the procedure in the Stanley et al. (1994) study dictated the exposure of both male and female adult mallards, the reproductive effects were primarily documented in female mallards. Therefore, female body weights for each representative species were used in the scaling algorithm to obtain the toxicological benchmarks.

In the second part of the Stanley et al. (1994) study, the ducklings which hatched from the eggs of the treated parents were also fed 25, 100 and 400 µg As/g feed for 14 days after hatching. Although no effects were seen at dose levels of 25 and 100, the ducklings in the 400 µg/g dose group had decreased growth rates and body and liver weights, suggesting a NOAEL of 100 µg/g and a LOAEL of 400 µg/g for developmental effects. Neither body weights nor food consumption data were provided for conversion from units of µg/g-diet to units of mg/kg-day. Therefore, assuming an average body weight of 240g (Lokemoen et al., 1990) and using the allometric equation (U.S. EPA, 1988a) presented above, a food consumption rate of 23 g/day was estimated. The 100 µg/g dose was converted to a NOAEL of 9.6 mg/kg-day, and the 400 µg/g dose was converted to a LOAEL of 38 mg/kg-day for developmental effects.

In another study, Camardese et al. (1990) fed mallard ducklings arsenic in doses of 30, 100 or 300 ppm beginning the day after hatching until 10 weeks of age. Reduced growth was seen in female ducklings given 30 ppm, although only male ducklings in the 300 ppm group exhibited decreases in growth compared to controls. This suggests a LOAEL of 30 ppm for pathological effects. Using a body weight of 780 g (Lokemoen et al., 1990), the allometric equation (U.S. EPA, 1988a) presented above, and a calculated food consumption rate of 49 g/day, the 30 ppm dose was converted to a daily dose of 1.9 mg/kg-day.

The Camardese et al. (1990) study was not considered suitable for the derivation of a benchmark value, since pathological effects do not clearly indicate that the fecundity of a wildlife population could be impaired. Data were available on the reproductive and developmental effects of As^{5+}, as well as on chronic survival. In addition the data set contained studies conducted over chronic and subchronic durations. Additional avian toxicity data were not identified for birds representing the terrestrial ecosystem. Therefore, the Stanley et al. (1994) study selected for the freshwater ecosystem, as discussed above, was also used to calculate terrestrial avian benchmark values.

Freshwater Community: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria (NAWQC) published by the EPA Office of Water. The FCV of 1.5E-01 mg/L As^{3+} developed by the GLWQI, and the Secondary Chronic Values (SCV) of 8.1E-03 mg/L for As^{5+} developed by the Oak Ridge National Laboratory were selected as the appropriate CSCL to use in this analysis. The GLWQI values were considered preferable to the NAWQC because: (1) the GLWQI values are based on the same methodology used to develop NAWQC (i.e., Stephan et al., 1985); (2) the NAWQC data set was augmented with previously unavailable acute and chronic toxicity data; and (3) species taxa used to generate the GLWQI values are suitable for national application since they include species and taxa found throughout the United States.

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metals concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). Consequently, the FCV for total arsenic was adjusted to provide a dissolved concentration as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). The conversion factor (CF) for arsenic of 1.00 for chronic effects was proposed to give a dissolved surface water CSCL; however, lacking a total concentration CSCL for arsenic (i.e., CSCLs only available for As^{3+} and As^{5+}), the CF could not be used. The use of CFs reflects the current Agency position on criteria development and regulatory application of metals; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). For example, the relationship between water characteristics (e.g., dissolved organic matter) and copper bioavailability and toxicity has been investigated in some detail (e.g., Allen and Hansen, 1996). Since, the arsenic CSCLs distinguish between As^{3+} and As^{5+}, it is likely that future research on conversion factors may result in changes to the estimated dissolved concentration for both valencies. All surface water CSCLs for arsenic are presented in Table 1.

Amphibians: No suitable subchronic or chronic studies were identified which studied the effects of arsenic toxicity on reproductive or developmental endpoints in amphibian species; however, several acute studies were identified characterizing arsenic toxicity. Review of data collected from six experiments indicate that the acute toxicity of arsenic ranges from 0.041 to 55 mg/L, with a geometric mean of 4.3 mg/L. Acute studies were conducted on various amphibian species (i.e., six amphibian species represented) during embryo and tadpole lifestages. Chemical exposures were conducted with sodium arsenite and arsenic trioxide (As^{3+}). The observation that the lowest acute amphibian value is approximately one order of magnitude below the FAV, of 0.36 mg arsenic/L and close to one order of magnitude below the FCV (0.15 mg arsenic (As^{3+})/L) determined for the freshwater community indicates that some amphibian species may be equally or more sensitive than other freshwater receptors. Given the lack of chronic amphibian data, a CSCL of 4.3 mg arsenic/L was derived based on acute toxicity. Since the CSCL is based on acute data (i.e., lethality), the severity of the potential adverse effects that this CSCL indicates should be noted. Investigations are ongoing to review the possibility of incorporating amphibian data into the NAWQC. Since amphibian species are more likely to breed in standing waters such as wetlands or ponds, the appropriateness of combining protective levels of amphibian receptors and the freshwater community is unclear at this time (Power et al., 1989; U.S. EPA, 1996).

Algae and Aquatic Plants: Relevant endpoints for aquatic plants focused on the ability of plants to support higher trophic levels as well as the ability to provide habitat for other species in the freshwater ecosystem. The criterias for aquatic plants and algae were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or 2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). Suter and Tsao (1996) reported a criteria of 4.8E-02 mg/L based on EC_{50} tests conducted on the green alga *Scenedesmus obliquus* with As^{5+}. As^{3+} has been observed as being less toxic to aquatic plants than the more prevalent As^{5+} form. Since this CSCL was developed from a single toxicity study on algae, confidence in the CSCL is low.

Benthic Community- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, CSCLs are developed estimating the 10th percentile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). These values are not NOAA standards; rather, they are used to rank sites based on the potential for adverse ecological effects. A second document evaluated for sediment CSCL development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the CSCL was changed. FDEP calculated the criteria (i.e., threshold effects level, TEL) from the geometric mean of the 50^{th} percentile of no effects data and the 15^{th} percentile of the low effects data. The NOAA data, used in both documents, is based on total metal concentrations in sediments, and the toxicity endpoints were measured on species of amphipods, arthropods, and bivalves in addition to a variety of community-based endpoints (e.g., abundance, mortality, species composition, species richness). The FDEP criterion was chosen above the NOAA criterion for the following reasons; (1) the same database was used for both the NOAA criteria and the FDEP criteria development only different derivation methods were used; (2) in most cases, the FDEP criterion was more conservative than the NOAA criteria because a larger portion of the low effects data was used in criteria development; (3) the marine TEL developed by the FDEP were found to be analogous to TELs observed in freshwater organisms (Smith et al., 1995).

The CSCL for arsenic was derived from 295 toxicity data points for low and no effects levels. For the screening level analysis of arsenic, the TEL of 7.2E+00 mg arsenic/kg sediment was selected as an appropriate sediment CSCL. Based on the quality and quantity of arsenic sediment data, the degree of confidence in the TEL value for arsenic was considered high (MacDonald, 1994).

Terrestrial Plants: As presented in Efroymson et al. (1997a), phytotoxicity criterias were selected by rank ordering the lowest observable effects concentration (LOEC) values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the criteria. Such LOECs applied to reductions in plant growth, yield, or seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. The selected CSCL for phytotoxic effects of arsenic in soils is 10 mg/kg soil, based on studies of the effects of As^{3+} and As^{5+} (Efroymson et al., 1997a). The derivation of the CSCL is based on 16 phytotoxicity studies on agricultural (e.g., barley, ryegrass) and silviculture (e.g., spruce) species measuring growth endpoints such as height and weight of shoots and roots, yield, and germination success. Considering this CSCL was based on multiple studies over a range of species, confidence in this criteria is high.

Soil Community: Because no adequate data to develop community-based CSCLs were identified, the CSCL for soil from earthworm studies presented in Efroymson et al., (1997b) of 60 mg/kg soil for arsenic was used. It is based on 1 study reporting effects on growth and reproduction of *Eisenia fetida*. Earthworms have been recognized to play important roles in promoting soil fertility, releasing nutrients, providing aeration and aggregation of soil, as well as being an important food source for higher trophic level organisms. Even though earthworms are important, basing a soil CSCL on one species does not ensure protection to the entire soil community given the complex processes and interactions characteristic of functional soil communities.

Table 1. Arsenic CSCLs in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Mammals	3.3E+00	mg/L water	Food web	River Otter	Byron et al., 1967
Birds	2.9E-02	mg/L water	Food web	Kingfisher	Stanley et al., 1994
Algae and Aquatic Plants	4.8E-02	mg/L water	Direct contact	*Scenedesmus obliquus*	Suter and Tsao, 1996
Freshwater Community					
As^{3+}	1.5E-01	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1995b
As^{5+}	8.1E-03	mg/L water	Direct contact	Aquatic biota	Suter and Tsao, 1996
Benthic Community	7.2E+00	mg/kg sediment	Direct contact	Benthos	MacDonald et al., 1994
Amphibians (acute effects)	4.3E+00	mg/L water	Direct contact	Various amphibian species	Power et al., 1989; U.S. EPA, 1996
Terrestrial					
Mammals	5.2E+02	mg/kg soil	Food web	Raccoon	Krasovskii et al., 1979
Birds	7.3E-01*	mg/kg soil	Food web	American woodcock	Stanley et al., 1994
Mammals	2.7E+01	mg/kg plant tissue	Food web	Meadow vole	Krasovskii et al., 1979
Birds	7.3E-01	mg/kg plant tissue	Food web	Northern bobwhite	Stanley et al., 1994
Plant Community	1.0E+01	mg/kg soil	Direct contact	Various plant speices	Efroymson et al., 1997a
Soil Community	6.0E+01	mg/kg soil	Direct contact	Soil invertebrates	Efroymson et al., 1997b

* This CSCL should not be used because it is below soil background concentrations (lowest mean background concentration 4.8 mg arsenic/kg soil) . This may be an artifact of our back-calculation method (i.e., calculating media-specific CSCLs from the benchmark study).

Ecotoxicological Profile for Ecological Receptors
Barium

This ecotoxicological profile on barium contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (5) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of barium so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

- Barium is present in the environment in one oxidation state (+2).
- Barium mobility in the environment is limited through the formation of relatively insoluble inorganic complexes and/or adsorption reactions.
- Two of the most important complexing agents are sulfate and carbonate.

Barium is a naturally occurring component of minerals that can be found in igneous rocks, sandstone, shale, and coal. Barium may be released to the environment naturally through the weathering of rocks and minerals or anthropogenically in association with mining, refining, production of barium and barium chemicals, and fossil fuel combustion. Barium exists in one oxidation state (+2). It is generally found complexed with inorganic constituents such as sulfate and carbonate or sorbed onto the soil substrate. Complexation with carbonate and sulfate and sorption to the soil substrate limit the mobility of barium in the environment.

II. Geochemistry of Barium in Various Ecological Media

Barium in Soils

- Barium mobility is limited by adsorption to metal oxides, hydroxides, clays, and organic matter.
- Barium mobility is also limited by the formation barium sulfate and barium carbonate precipitates.
- Mobility may be increased through the formation of water soluble salts, specifically complexation with nitrate, chloride, and hydroxide ions.
- The solubility, and resultant mobility, increase with decreasing pH.

Barium is relatively abundant in the earth's crust and is found in most soils. Although barium has been measured at concentrations as low as 10 parts per million (ppm) and as high as 10,000 ppm, typical concentration values for barium in soil range from 100 to 3,500 ppm (Dragun, 1988). In cultivated and uncultivated soil samples collected during field studies, barium concentrations ranged from 15 to 1,000 ppm (mean concentration of 300 ppm) for B horizon soils in the eastern United States and from 70 to 5,000 ppm (mean concentration of 560 ppm) for this same soil horizon in the western United States. Barium content ranged from 150 to 1,500 ppm for surface horizon soils collected in Colorado (mean concentration of 550 ppm).

Barium is present in the environment in one oxidation state (i.e., the +2 oxidation state). In soils, barium may be "fixed" or immobilized as a result of chemisorption and precipitation. Chemisorption refers to the formation of a covalent bond between an adsorbed element such as barium and a mineral surface. Barium adsorbs onto metal oxides, hydroxides, clays, and organic matter in soil. The cation exchange capacity of the soil largely controls the retention of barium in soils. The larger the cation exchange capacity, the more likely barium will be immobilized in the soils.

Precipitation can also immobilize barium in soils. Barium can form precipitates in the presence of carbonate, sulfate, and phosphate. The two most important precipitates under environmental conditions are barium carbonate ($BaCO_3$) and barium sulfate ($BaSO_4$). Hence, soils with high calcium carbonate content and/or elevated concentrations of sulfate ions limit the mobility of barium.

Barium may also form water soluble salts with nitrate, chloride, and hydroxide ions in soil. Barium is more mobile and is more likely to be leached from soils in the presence of these complexing agents due to increased solubility. In general, the solubility of barium compounds increases with decreasing pH. Barium mobility may also be increased when complexed with humic and fulvic acids, which results in a reduction in adsorption capacity.

Barium in Surface Water

C Barium forms complexes in surface water with sulfate and carbonate and precipitates out of solution. Precipitation decreases the dissolved phase burden in surface waters.

C Barium concentrations in surface water increase in the presence of chloride, nitrate, and hydroxide. This is due to the formation of water soluble complexes.

Barium has been measured at concentrations ranging from 2 to 380 Fg/L (mean concentration range of 10 to 60 Fg/L) in approximately 99 percent of the samples collected from surface water and finished public water supplies.

Although barium may be present in surface water as the barium ion (Ba^{2+}), complexation with naturally-occurring constituents in water is common. Two of the most important complexing agents are sulfate and carbonate. At pH values less than 9.3, barium sulfate ($BaSO_4$) is favored. At pH values greater than 9.3, barium carbonate ($BaCO_3$) prevails. Since the solubilities of $BaSO_4$ and $BaCO_3$ are relatively low, barium is likely to precipitate out of solution as an insoluble salt in the presence of these two complexing agents. Barium may also form salts of low solubility with arsenate, chromate, fluoride, oxalate, and phosphate ions, furthering limiting dissolved concentrations in surface water.

Barium concentrations in surface water increase in the presence of chloride, nitrate, and hydroxide. Specifically, barium may form complexes with chloride, nitrate, and hydroxide in natural waters. These complexes are characterized as water soluble and are frequently detected in aqueous environments.

Barium in Sediments

C Barium in sediments is found largely in the form of barium sulfate.

Sedimentation of suspended solids results in the mass removal of barium from surface water systems to the underlying sediments. Barium in sediments is found largely in the form of barium sulfate ($BaSO_4$). Coarse silt sediment in a turbulent environment will often grind and cleave the barium sulfate from the sediment particles, leaving a building up of $BaSO_4$.

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystems
Data on the effects of barium on freshwater organisms are limited. Results from daphnid experiments suggest that high concentrations of barium may impair the growth and reproduction of zooplankton populations. Depending on the duration (i.e., 24 and 48 hours), acute toxicity (LC_{50}s) to daphnids ranges from 14.5 to greater than 530 mg/L (Ba^{2+}); however, a chronic 3-week daphnid bioassay resulted in an LC_{50} of 13.5 mg/L. No effects to daphnids were observed at concentration of 68 mg/L (Ba^{2+}) after 48 hours, but after 3 weeks reproduction was impaired, mean body weight was depressed, and metabolic activity was decreased at 5.8 mg/L (Ba^{2+}) (LeBlanc,1980; Biesinger and Christensen 1972). The large range between these results may be indicative of differing water quality parameters which were not identified in the results of these studies.

Terrestrial Ecosystems
Results of experimental animal studies show that barium toxicity varies widely with dosage form, route of exposure, species, and age, as well as solubility of the barium compound administered (U.S. EPA, 1987c). Injected barium salts in animals are highly toxic, but most of them are insoluble (Schroeder and Mitchener, 1975a). Acute oral exposure, by gavage, to barium chloride resulted in LD_{50}s of 220 mg/kg diet for weanling rats and 132 mg/kg diet for adults (U.S. EPA, 1987c). Schroeder and Mitchener (1975a,b) treated rats and mice with 5 mg/L barium acetate in drinking water throughout the animals' lives. At various intervals, female rats exhibited increased longevity and male mice showed a slight reduction in longevity. However, they observed no consistent trends in adverse effects. The study did not establish a dose-response relationship for reproductive, developmental, or growth effects, or any other kind of effect that might impair the ability of an animal population to sustain itself. Studies conducted by Tardiff et al. (1980) administered barium chloride in drinking water (0, 10, 50, or 250 ppb barium) to 4-week-old rats for 4, 8, or 13 weeks. There were no observed adverse effects (Tardiff et al., 1980). A final study conducted by Tarasenko et al. (1977) administered barium chloride orally to pregnant rats. They state that the offspring of the treated females showed increased mortality, suggesting that barium may have embryotoxic effects. However, the study did not report any data to support the significance of this finding. Limited effects data were available on terrestrial plants and soil invertebrates; however, these receptors appear to be more resistant that other ecological receptors to barium exposure (Table 1).

IV. Bioaccumulation Potential

Freshwater Ecosystems
For organisms in the freshwater environment, exposure to barium occurs primarily through ingestion of contaminated media or food. As barium is similar in chemistry to calcium, most barium retained in the body will end up in bone tissue. Organisms that consume bone material may have higher exposures. Bioconcentration of barium by aquatic organisms (e.g., fish and marine organisms) occurs; however, sufficient data to determine bioconcentration factors (BCFs) for freshwater fish or other aquatic invertebrates were not identified. Investigations are ongoing to identify studies that further characterize the bioaccumulation of barium in ecological receptors.
Terrestrial Ecosystems
Bioaccumulation in terrestrial invertebrates, plants, and small mammals is currently being investigated at Oak Ridge National Labs. Bioaccumulation and bioconcentration factors (BAFs and BCFs) for terrestrial plants, invertebrates, and small mammals have been proposed from

review of primary literature sources. The 90th percentile of the bioaccumulation data for these receptors derived from both laboratory and field studies were used to determine terrestrial food chain exposures. For earthworms and terrestrial plants there were no proposed BAFs. For small mammals, based on 14 reported values assessing the transfer of barium from soil to small mammals, a BAF of 0.11 was proposed (Sample et al., 1997; Samples et al., 1998). These values were used to model food chain exposures to terrestrial species for this analysis, because currently, they stand as the most comprehensive collection of bioaccumulation data for terrestrial ecological receptors (Sample et al., 1997; 1998a; 1998b).

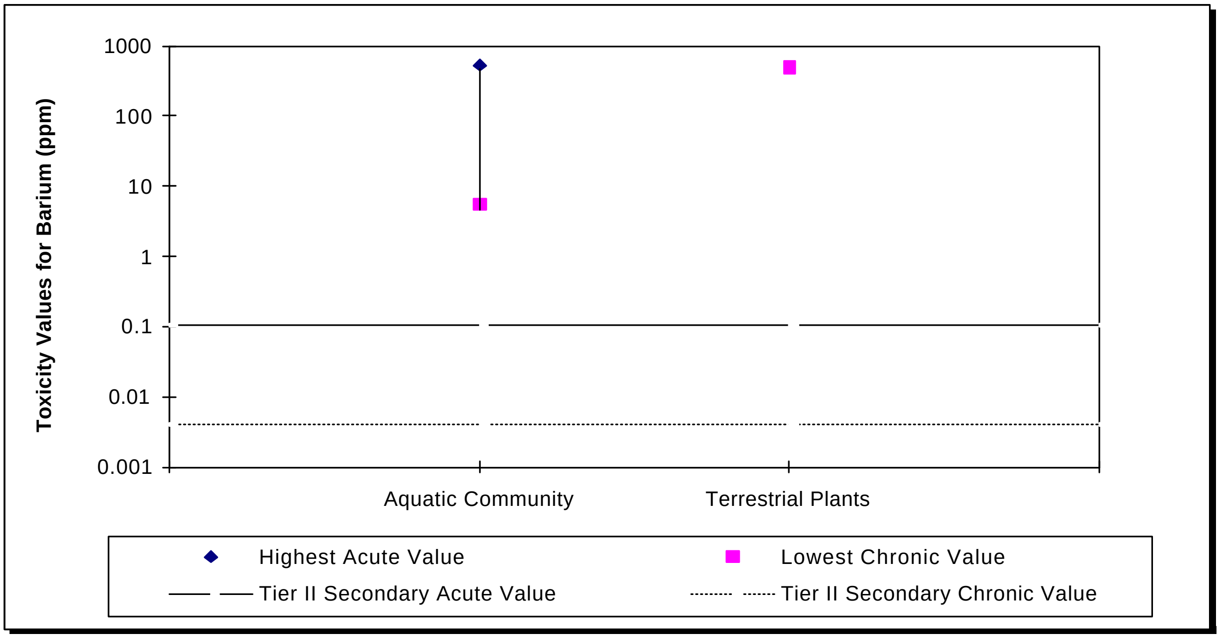

Figure 1. Barium: Effects Ranges for Ecological Receptors

V. CSCL Development

The benchmark values presented in this section for mammals and birds (e.g., daily dose values) were used to derive protective media-specific CSCLs as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor and the potential bioconcentration in prey, a protective concentration (i.e., CSCLs) in soil, plants or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. By protecting the more sensitive species, other receptors are likely to be protected as well.

Mammals: No suitable subchronic or chronic studies were identified which studied the effects of barium toxicity on reproductive or developmental endpoints in mammalian species.

Birds: Study done by Johnson et al. 1960 (as cited by Sample et al., 1996) were used to derive CSCL for birds. They examined barium's effects on the reproduction of chicks with a diet of 250, 500, 1000, 2000, 4000, 8000, 16000, and 32000 ppm. Chicks treated with 4000 ppm of barium experienced mortality. Because the study was conducted during a critical growth period, a NOAEL of 2000 ppm and a LOAEL of 4000 ppm can be inferred for developmental effects. As reported by Sample et al. (1996), the NOAEL for chicks is 20.8 mg/kg-day and the LOAEL is 41.7 mg/kg-day. Additional avian toxicity data were not identified for birds representing the terrestrial ecosystem. Therefore, the study was used to derive CSCLs for avian species in both the freshwater and terrestrial ecosystems.

Freshwater Community: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria

(NAWQC) published by the EPA Office of Water. Neither of these criteria have been developed for barium; therefore, a Secondary Chronic Value (SCV) was calculated. SCVs are calculated by analogous methods used to derived FCVs for both the GLWQI and NAWQC. However, when the eight data requirements for developing the FCV were not available, the SCV criteria was based on one to seven of the eight required criteria. For barium, the SCV of 4.0E-03 mg/L developed by Suter and Tsao (1996) for total barium was selected as the appropriate CSCL to use in this analysis. The SCV for barium was derived from 12 data points derived from toxicity endpoints found in fish and aquatic invertebrates. From these data, an SAV of 1.136E-01 mg/L and SACR of 28.29 were calculated. The resulting ratio of these values (i.e., SAV/SACR) determined the SCV of 4.0E-03 mg/L (Suter and Tsao, 1996).

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metals concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). EPA has developed conversion factors (CFs) to estimate probable dissolved concentrations of metals in surface waters given a total metal concentration as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). A CF is not yet available for barium; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). The final surface water CSCL for barium is presented in Table 1.

Amphibians: No suitable subchronic or chronic studies were identified which studied the effects of barium toxicity on reproductive or developmental endpoints in amphibian species. Further, no acute toxicity data on amphibians were identified in the literature.

Algae and Aquatic Plants: Relevant endpoints for aquatic plants focused on the ability of plants to support higher trophic levels as well as the ability to provide habitat for other species in the freshwater ecosystem. The criterias for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or (2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). Data were not identified in Suter and Tsao (1996) or in AQUIRE; thus, no CSCL was set.

Benthic Community- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, criteria are developed estimating the 10th percentile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). For our purposes, the ER-L was considered an appropriate criteria for freshwater sediment biota. A second criteria document evaluated for sediment CSCL development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the criteria was changed. Neither of these documents, or alternative references such as ORNL, proposed a suitable sediment criteria for barium; therefore, no CSCL on barium could be developed.

Terrestrial Plants: As presented in Efroymson et al. (1997a), phytotoxicity criterias were selected by rank ordering the lowest observable effects concentration (LOEC) values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the criteria. Such LOECs applied to reductions in plant growth, yield, or seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. The selected criteria for phytotoxic effects of barium in soils is 500 mg/kg, based on a reduction in shoot growth of barley. This value was the lowest LOEC presented by Efroymson et al. (1997a). The derivation of the CSCL is based on two phytotoxicity studies on agricultural (e.g., barley, beanbush) species measuring growth endpoints such shoot and root weight. Considering this CSCL was based on limited phytotoxicity data on only a few species, confidence in this criteria is low.

<u>*Soil Community*</u>: Because no adequate data to develop community-based CSCLs were identified, CSCLs for soil from microbial effects presented in Efroymson et al. (1997b) of 3000 mg barium/kg soil was proposed; it is based on 1 reported effect on microbial activities from barium exposure. The toxicity endpoints measured in microorganisms included effects such as enzyme activities, nitrogen transformation, and mineralization. These functions have been recognized to play important roles in nutrient cycling, which provides nutrients in available forms to plants. Even though microbial processes are important in soil, using this CSCL may have limited utility. Basing a CSCL on only one species or taxa does not consider the complex processes and interactions characteristic of functional soil communities. Community-based CSCLs should be used as they become available. Confidence in this CSCL is low.

Table 1. Barium CSCLs in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Freshwater Community Total	4.0E-03	mg/L water	Direct contact	Aquatic biota	Suter and Tsao, 1996
Terrestrial					
Birds	2.4E+02	mg/kg soil	Food web	American woodcock	Sample et al., 1996
Birds	2.8E+02	mg/kg plant tissue	Food web	Northern bobwhite	Sample et al., 1996
Plant Community	5.0E+02	mg/kg soil	Direct contact	Barley and bush beans	Efroymson et al., 1997a
Soil Community	3.0E+03	mg/kg soil	Direct contact	Soil invertebrates	Efroymson et al., 1997b

Insufficient data for aquatic birds, aquatic and terrestrial mammals, algae and aquatic plants, and the benthic community

Ecotoxicological Profile for Ecological Receptors
Beryllium

This ecotoxicological profile on beryllium contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (5) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of beryllium so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

Beryllium is a rare metallic element that occurs in nature in variety of compounds and minerals. Background concentrations in soils of the United States range from less than 1 ppm to 15 ppm, with a mean concentration of 0.92 ppm (Dragun and Chiasson, 1991). Its average concentration in air is 0.03 ng/m^3, although in cities it is greater by about a factor of 10. The geometric mean concentration in surface waters of the United States is 70 µg/L. Beryllium is present in air mostly as fine particles, which may remain in the atmosphere for up to 10 days before being deposited on soil or water. In both water and soil, most beryllium will be bound to particles, with only a small fraction in soluble form. Generally, beryllium is immobile, although under some environmental conditions, it may become more soluble and mobile (ATSDR, 1993a).

The toxicity of beryllium varies greatly among its different compounds, and depends primarily on solubility. Acute exposure to inhaled beryllium can be fatal in animals, causing lung damage. Chronic exposure to inhaled beryllium has caused systemic effects and sometimes death; however chronic oral exposures have not been reported to cause increased mortality. The reproductive effects of oral exposure are unclear. Beryllium is extremely toxic to warmwater fish in soft water. Beryllium bioconcentrates in fish, and could potentially bioconcentrate in sediment-dwelling organisms, but biomagnification in food chains has not been observed (ATSDR, 1993a).

II. Geochemistry of Beryllium in Various Ecological Media

Beryllium in Soils

Beryllium (Be) compounds are naturally present in soils. The average concentration of beryllium in the Earth's crust is 2.8-5.0 mg/kg (Reeves, 1986). Typical beryllium concentrations in soil range from 0.01 to 40.0 mg/kg, with a mean of 0.3 mg/kg (Bowen, 1979). USGS soil survey data gave a mean soil beryllium concentration of 0.6 mg/kg (Eckel and Langley, 1988).

- ! Beryllium only exhibits a +2 valence state.
- ! Beryllium should be strongly adsorbed in most soils.
- ! Beryllium may adsorb onto clay surfaces at low pHs, and may remain as insoluble complexes at higher pHs.
- ! The mobility of beryllium in soils should be limited.

Beryllium should be strongly adsorbed in most soils because it displaces divalent cations which share common sorption sites (Fishbein, 1981). Beryllium is chemically similar to aluminum, and, therefore, may be expected to adsorb onto clay surfaces at low pHs, and may remain precipitated as insoluble complexes at higher pHs (Callahan et al., 1979). As a result, beryllium should have limited mobility in soils.

Beryllium in Surface Waters

In water, soluble beryllium salts are hydrolyzed to form relatively insoluble beryllium hydroxide, which has a low solubility within the pH range of most natural waters (Callahan et al., 1979). Eckel and Jacob (1989) determined the estimated geometric mean concentration of total beryllium in United States' surface waters as 70 ng/l (from ambient lake and stream water monitored by the U.S. Geological Survey and EPA STORET database from ~1960-1988). The total beryllium concentration in the Great Lakes ranged from a median of <4 to 120 ng/L (Rossman and Barres, 1988). The total beryllium concentration in various surface waters ranged from 10 to 100 ng/L (Bowan, 1979).

- ! In water, soluble beryllium salts are hydrolzed to form beryllium hydroxide. Beryllium hydroxide has a low solubility within the pH range of most natural water;
- ! In sea water, beryllium has a strong tendency to form hydrolysis products and exists mainly as $Be(OH)^+$ and $Be(OH)_2^0$.

Beryllium in Sediments

In most natural waters, beryllium should be predominantly adsorbed onto particulate matter or sediment. In the Great Lakes, beryllium is present in the sediment at concentrations several orders of magnitude greater than in the overlying water (ATSDR, 1993). In sediment, beryllium is usually associated with the clay fraction, which is expected from the similar geochemistries of aluminum and beryllium. Some sedimentary beryllium may also form through precipitation of insoluble complexes.

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystems

In experimental animals, beryllium ingested orally is minimally absorbed by the gastrointestinal tract, and most is excreted very rapidly. In contrast, animal studies indicate that after inhalation exposure, most beryllium is retained (Browning, 1969). Soluble beryllium compounds as Be^{2+} have been found to be transformed into insoluble forms in the lungs, resulting in long retention times there (Be^{2+}) (U.S. EPA, 1986g). After absorption, some is deposited in bone, and the rest is generally excreted. Beryllium exposure may have adverse effects on enzyme production and function, lung and other organ tissue and function (Be^{2+}). It has teratogenic effects on snails, and has inhibited limb regeneration in salamanders. Acute exposure to concentrations of as low as 87 µg/L are toxic to fish, and chronic exposure to 3 µg/L is toxic to daphnids. Acute toxicity can be over 100 times more toxic in soft water than in hard water (Sittig, 1980). Similar observations were seen with amphibian species. Amphibian species (i.e., *Ambystoma maculatum* and *Ambystoma opacum*) exposed to beryllium for 96 hours indicated acute toxicity (LC_{50}) ranging from 3.1 to 8.3 mg/L in test media with low water hardness (i.e., 20 to 25 mg $CaCO_3$/L). However, a much higher tolerance to exposure of amphibian species was noted in test media with water hardness of 400 mg $CaCO_3$/L. In studies with higher water hardness, acute toxicity was indicated in the range of 18 to 32 mg/L. No data reporting chronic effects to amphibians was identified (Power et al., 1989; U.S. EPA, 1996).

Terrestrial Ecosystems

As indicated for freshwater mammals and birds, minimal amounts of ingested beryllium are absorbed, and most is excreted very rapidly whereas inhaled beryllium is retained as insoluble compounds in lung and bone tissues (Browning, 1969; U.S. EPA, 1986g). The lung is often the first target organ of beryllium disease (Hamilton and Hardy, 1974). Acute inhalation exposures to beryllium have been found to cause effects in experimental mammals (U.S. EPA, 1986g). In some species, exposure to beryllium causes hypersensitivity (Hamilton and Hardy, 1974). Chronic and acute inhalation studies on experimental animals have demonstrated a number of reproducible toxic effects, such as osteosarcoma, lung neoplasia, and death (Hamilton and Hardy, 1974; U.S. EPA, 1986g; ATSDR, 1993).

Fewer investigations of oral exposure to beryllium have been conducted. Chronic exposure to high doses of beryllium carbonate has been found to cause rickets in experimental animals (U.S. EPA, 1986g). Schroeder and Mitchener (1975a,b) dosed mice and rats beryllium in drinking water at 5 mg/L until natural death; however, consistent differences in weight and longevity were not found.

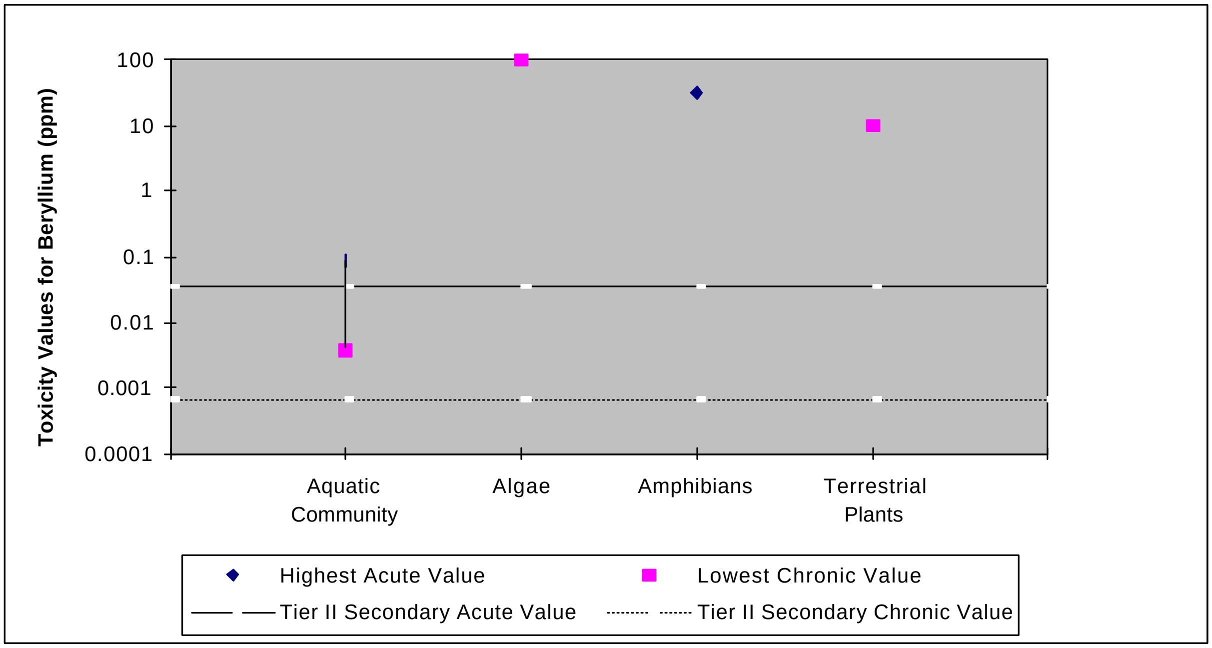

Figure 4: Beryllium: Effects Ranges for Ecological Receptors

Current understanding of beryllium's reproductive and teratogenic effects on animals are restricted to the results of a few studies administering doses via injection (e.g., Ridgway and Karnofsky, 1952; Mathur et al., 1987). Although some studies found that beryllium can cause such effects, these findings are not consistent (U.S. EPA, 1986g; Leonard and Lauwerys, 1987; ATSDR, 1993a). In some terrestrial plant species, effects (e.g., inhibited growth and survival) are indicated at beryllium concentrations of 10 to 25 mg/kg soil (Efroymson et al., 1997a). No data was identified to characterize the effects of beryllium to soil biota (e.g., earthworms).

IV. Bioaccumulation Potential

Freshwater Ecosystems

Bioconcentration factor (BCF) of 19 (L/kg) for fish was used. This is based on whole-body measured BCFs of bluegill sunfish (*Lepomis macrochirus*) with 28 days of exposure (Barrows et al., 1980). As noted by Barrows et al. (1980), beryllium did not appear to have reached steady-state during the exposure period, and the BCF of 19 is calculated as the maximum bioconcentration factor. Because the actual BCF of beryllium on fish may be higher, confidence in this value is low; additionally, this value being used in the Great Lakes Initiative (Stephan, 1993). Insufficient data were identified to determine the bioconcentration factor (BCF) value in other aquatic organisms.

Terrestrial Ecosystems

Data were not identified to determine bioconcentration factors (BCFs) for terrestrial vertebrates or terrestrial invertebrates, earthworms, and plants.

V. CSCL Development

The benchmark values presented in this section for mammals and birds were used to derive protective media-specific CSCLs as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor and the potential bioconcentration in prey, a protective concentration (i.e., CSCLs) in soil, plants or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. It is assumed that by protecting the more sensitive species, the other receptors are protected as well.

Mammals: No suitable sub-chronic or chronic studies which studied the effects of beryllium toxicity on reproductive or developmental endpoints in mammalian species were identified.

Birds: No suitable sub-chronic or chronic studies which studied the effects of beryllium toxicity in avian species were identified.

Freshwater Community: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria (NAWQC) published by the EPA Office of Water. Neither of these reports presented a criteria for beryllium; therefore, a Secondary Chronic Value (SCV) was calculated. SCVs are calculated by analogous methods used to derived FCVs for both the GLWQI and NAWQC. However, when the eight data requirements for developing the FCV were not available, the SCV criteria was based on one to seven of the eight required criteria. For beryllium, the SCV of 6.6E-04 mg/L developed by Suter and Tsao (1996) for total beryllium was selected as the appropriate CSCL to use in this analysis. The SCV for beryllium was derived from 27 data points derived from toxicity endpoints found in fish and aquatic invertebrates. From these data, an SAV of 3.5E-2 mg/L and SACR of 52.88 were calculated. The resulting ratio of these values (i.e., SAV/SACR) determined the SCV of 6.6E-04 mg/L (Suter and Tsao, 1996).

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metals concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). EPA has developed conversion factors (CFs) to estimate probable dissolved concentrations of metals in surface waters given a total metal concentration as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). A CF is not yet available for beryllium; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). The final surface water CSCL for beryllium is presented in Table 1.

Amphibians: No suitable subchronic or chronic studies were identified which studied the effects of beryllium toxicity on reproductive or developmental endpoints in amphibian species. Based on acute exposures of amphibian species, a geometric mean of 11 mg beryllium/L was derived as the CSCL indicating potential acute affects to amphibian species. The studies used to develop this CSCL were conducted at water hardness media concentrations of 20 and 400 mg $CaCO_3$/L. The species *Ambystoma maculatum* and *Ambystoma opacum* at larva stages were exposed via direct contact to beryllium sulfate for 96 hours to generate LC_{50}s ranging from 3.1 to 32 mg/L. The acute

NAWQC for the freshwater community set at 0.035 mg beryllium/L falls over two orders of magnitude below the proposed acute CSCL for amphibians suggesting that receptors of the freshwater community (e.g., fish, aquatic invertebrates) may be more sensitive to acute exposures than amphibians; however, more data is needed to confirm this observation since derivation methods and data assumptions between development of the acute NAWQC and this amphibian CSCL are very different. Investigations are ongoing to review the possibility of incorporating amphibian data into the NAWQC. Since amphibian species are more likely to breed in standing waters such as wetlands or ponds, the appropriateness of combining protective levels of amphibian receptors and the freshwater community is unclear at this time (Power et al., 1989; U.S. EPA, 1996).

<u>*Algae and Aquatic plants*</u>: Relevant endpoints for aquatic plants focused on the ability of plants to support higher trophic levels as well as the ability to provide habitat for other species in the freshwater ecosystem. The CSCLs for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or 2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). The aquatic plant CSCL for beryllium is 100 mg/L based on reduction in autotrophic growth rates in *Chlorella vannieli* (Suter and Tsao, 1996).

<u>*Benthic Community*</u>- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, criteria are developed estimating the 10th percentile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). For our purposes, the ER-L was considered an appropriate CSCL for freshwater sediment biota. A second criteria document evaluated for sediment criteria development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the criteria was changed. Neither of these documents developed a suitable sediment CSCL for beryllium. A value (3.7 E-02 mg beryllium/kg sediment) was proposed by U.S. EPA, 1997 in the *Protocol for Screening Level Ecological Risk Assessment at Hazardous Waste Combustion Facilities*; however, since this criteria was derived by extrapolation from the water quality criteria and lacked supporting ecotoxicity data on benthic invertebrates, we did not selected this value. Therefore, no CSCL on beryllium could be developed.

<u>*Terrestrial Plants*</u>: As presented in Efroymson et al. (1997a), phytotoxicity CSCLs were selected by rank ordering the lowest observable effects concentration (LOEC) values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the CSCL. Such LOECs applied to reductions in plant growth, yield, or seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. The proposed CSCL for phytotoxic effects of beryllium is 10 mg/kg, a LOEC based on unspecified toxic effects on plants grown in soil with a concentration of 10 ppm beryllium (Efroymson et al., 1997a). Since the CSCL was based on a single study reporting unspecified effects and did not indicate the form of beryllium applied to test soils or the terrestrial plant

species exposed, this criteria study was not appropriate for CSCL development. No further studies were identified, so no CSCLs could be developed for the terrestrial plant community.

Soil Community: No appropriate studies have been identified to derive a soil CSCL for beryllium.

Table 1. Beryllium CSCLs in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Algae and Aquatic Plants	1.0E+02	mg/L water	Direct contact	*Chlorella vannieli*	Suter and Tsao, 1996
Freshwater Community Total	6.6E-04	mg/L water	Direct contact	Aquatic biota	Suter and Tsao, 1996
Amphibians (acute effects)	1.1E+01	mg/L water	Direct contact	Various amphibian species	Power et al., 1989; U.S. EPA, 1996

Insufficient data for birds, mammals, terrestrial plants, benthic community, and soil community

Ecotoxicological Profile for Selected Ecological Receptors
Cadmium

This ecotoxicological profile on cadmium contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (5) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of cadmium so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

Cadmium (Cd), a rare naturally occurring heavy metal, is a known teratogen, carcinogen, and a probable mutagen in some terrestrial and aquatic biota (Hoffman et al., 1995). Conflicting evidence exists regarding the biological requirement or beneficial role of cadmium to organisms. However, it is clear that low concentrations of cadmium in exposure media or food items may elicit adverse effects in a wide range of ecological receptors. Although biomagnification of cadmium in the food chain has not been demonstrated, cadmium does bioaccumulate in invertebrate and vertebrate species, microorganisms, and plants.

The bioavailability and expression of toxicity are a function of the physical characteristics of the exposure setting (e.g., pH, clay content, particle size, hardness, organic carbon) and the chemical properties of the cadmium species. The free ionic form of cadmium is more toxic to aquatic biota than cadmium that is complexed with dissolved organic matter or with soluble particulate matter (SPM) or colloidal matter. The low solubility and volatility of cadmium tends to favor soils and sediments as cadmium sinks. Based on its persistence in the environment and its toxicity to wildlife, cadmium contamination may present a significant threat to ecosystems at all levels of biological organization.

II. Geochemistry of Cadmium in Various Ecological Media

Cadmium in Soils

Cd can be present in soil as free cadmium compounds or in solution as the Cd^{2+} ion dissolved in interstitial water (ATSDR, 1989). The speciation of cadmium in soils can vary spatially and temporally depending on the particular geochemical conditions of the system considered. The pH, organic matter content, and the presence of other inorganic ligands for example, can be important controls on cadmium speciation in soils. In high acidity soils, the release of Cd^{2+} and its uptake by

- The speciation of cadmium is dependent on the soil geochemistry.
- For soil types ranging from sand to silty clay loam, the adsorption of Cd^{2+} is highly pH dependent.
- Cadmium sorption increased with increasing pH between pH 3 and pH 10.
- Organic matter seems to be a major adsorption site for cadmium. Iron, aluminum, and manganese oxides were less important than organic matter for adsorbing cadmium.

plants is favored (ATSDR, 1989).

Lee et al. (1996) investigated the sorption of Cd^{2+} on 15 New Jersey soils. They considered the influence of pH, iron, manganese, and aluminum oxide concentrations, and organic matter in the soil on cadmium sorption. The soil type ranged from sand to silty clay loam and the different soils had different pH, clay content, and organic matter content. From the results of their experiments, Lee et al. (1996) concluded that Cd^{2+} adsorption is highly pH dependent. The adsorption of Cd^{2+} increased with increasing pH between pH 3 and pH 10. Moreover, different soil types had very different adsorption abilities. Organic matter seemed to be a major adsorption site for binding Cd^{2+}. Iron, aluminum, and manganese oxides were less important than organic matter for adsorbing cadmium.

Cadmium in Surface Water

Cadmium is relatively mobile in the aqueous environment. In natural waters, cadmium can exist as the hydrated ion, as inorganic complexes, and as organic complexes. The distribution of trace elements such as cadmium between dissolved and particulate forms plays a fundamental role in controlling their behavior in aquatic systems.

- Cadmium is relatively mobile in the aqueous environment.
- Cadmium can exist as the hydrated ion, inorganic complexes, and organic complexes.
- Complexation with dissolved organic carbon and association with SPM are important in controlling the behavior of cadmium.
- Cadmium can be present in association with colloidal material in natural waters.

In rivers, the behavior of cadmium is primarily controlled by geochemical processes (Hart and Hines, 1995). Cadmium behavior is heavily dependent upon the balance between complexation with dissolved organic matter and association with suspended particulate matter (SPM) and colloidal matter. Biological processes have only a minor influence on its behavior.

A recent review of trace element concentrations in uncontaminated rivers (Hart and Hines, 1995) reported cadmium concentrations in rivers in the range ~10-90 ng/l for cadmium in the dissolved (< 0.4 Fm) phase.

Shafer et al. (1997) determined that the partitioning behavior (between dissolved (< 0.4 Fm) and particulate (> 0.4 Fm) phases) characteristic of cadmium in two Wisconsin rivers lay between that of copper and of zinc. Copper exhibited very strong complexation by dissolved organic carbon (DOC) and relatively low clay partitioning, whereas zinc appeared to have intermediate affinity for both DOC and clays. Comparing the characteristic behavior of lead (Pb), zinc (Zn), cadmium (Cd), and copper (Cu), partitioning of the metals to SPM followed the trend Pb>Zn>Cd>Cu and the association with DOC appeared to follow the trend Cu>Cd>Zn>Pb (Shafer et al., 1997).

Benoit (1995) determined cadmium concentrations in fresh water from three rivers in the northeast United States and investigated the relationship between cadmium in particulate, colloidal, and “truly” dissolved (i.e., occurring as individual solvated ions) phases. Total cadmium concentrations in river water ranged from 13 to 684 ng/l. Dissolved cadmium concentrations ranged from 3 to 235 ng/l. The partition coefficient, K_d, was independent of major ion chemistry and pH. Partitioning between (0.45 Fm) filter-retained and filtrate (< 0.45 Fm) fractions exhibited a dependence on the concentration of total suspended solids (Benoit, 1995). This phenomenon, the particle concentration effect, can be explained by the contribution of cadmium bound to colloids which are included in the filter-passing fraction of conventionally "dissolved" trace elements (Benoit, 1995 and references therein).

Cadmium in Sediments
Concentrations of cadmium in sediments are at least one order of magnitude greater than those in the overlying water column (Callahan et al., 1979, cited in ATSDR, 1993). Cadmium sulfide (which has a low solubility product) can precipitate in sediments under reducing conditions that produce sulfide (ATSDR, 1989). Subsequent exposure of cadmium sulfide bearing sediments to oxygen can result in the oxidation of the sulfide phase and the release of solubilized Cd^{2+} into solution (ATSDR, 1989).

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards (i.e., NAWQC) for freshwater communities (FCV or secondary values) are included for both acute and chronic endpoints. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystems
The toxicity of cadmium is well characterized in the primary literature showing that concentrations exceeding 10 ppb result in adverse effects in freshwater species (e.g., mortality, decreased growth, and decreased reproductive capacity). Surface water concentrations ranging from 7 to 34 µg/L have been reported to cause acute effects (e.g., mortality) in fish. Salmonid fishes are among the more sensitive biota in freshwater environments with toxic effects reported at concentrations in the range of 0.75 to 7.7 µg/L (Cd^{2+}) (Jensen and Bro-Rasmussen, 1992; Hoffman et al., 1995). For example, Atlantic salmon alevin fry have exhibited decreased growth rates at aqueous concentrations of 2.0 µg/L, with no observable impairment at low exposures of 0.2 µg/L (Cd^{2+}) (Peterson et al., 1983). In aquatic invertebrates, adverse chronic effects have been documented at relatively low dissolved cadmium concentrations, 0.15 µg/L to 3.0 µg/L, both in the laboratory and in the field (Hoffman et al., 1995). Concentrations that elicit acute effects in aquatic invertebrates range from 7 µg/L to 35 mg/L. In algae, decreased population growth rates were observed at concentrations of 3,700 µg cadmium/L (Cd^{2+}) (Canton and Slooff, 1981). In amphibians, cadmium exposures have been reported to adversely effect survival, reproductive success, and development (Cd^{2+}) (Power et al., 1989). Acute effects were observed in various amphibian species in the range of 470 to 850 ppb cadmium while chronic effects were observed between 45 to 227 ppb cadmium (U.S. EPA, 1996). The sediment community has demonstrated adverse effects in the field when exposed to cadmium concentrations of 5 to 20 mg/kg. Impacts associated with these concentrations include mortality, decreased abundance, and altered diversity (i.e., shifts in abundance to more metal tolerant species).

Terrestrial Ecosystems
Receptors characteristic of terrestrial systems (i.e., mammals, birds, the soil community, and terrestrial plants) have also been adversely impacted by exposure to cadmium. Numerous laboratory studies have documented the effects of cadmium toxicity in terrestrial mammals and

birds. Chronic oral exposures ranging from 3.5 to 7.5 mg Cd/kg body weight have been associated with decreased body weight and growth in laboratory rodents (Shore and Douben, 1994). Reproductive effects in a variety of species are also reported. Oral exposures of 0.1 µg/L resulted in reproductive failure in mice and doses of 4 mg/kg-day resulted in decreased fetal weight in exposed rats (Schroeder and Mitchener 1971b, Sorell and Graziano 1990). Available studies reported reproductive LOAEL's at dietary concentrations ranging from 4.0 to 10.0 ppm Cd for rats. Reproductive effects in avian species have also been reported. Mallard duck hens orally exposed to cadmium at 19 mg/kg-day for 90 days exhibited suppressed egg production (White and Finley, 1978). Japanese quails exposed from birth to six weeks of age to oral doses of 75 ppm cadmium developed testicular hypoplasia (Richardson et al., 1974). In terrestrial plants, adverse effects to growth endpoints were observed in the range of 1-200 mg/kg soil (Efroymson et al., 1997a). Data identifying toxicity to earthworms, a vital member of the soil community, was also identified. Adverse effects to chronic earthworm endpoints (i.e., cocoon production) were indicated by concentrations ranging from 10 to 215 mg/kg soil; further, adverse impacts to acute endpoints (i.e., earthworm mortality) were indicated by exposures ranging from 440 to 1840 mg/kg soil (Efroymson et al., 1997b). Adverse effects to terrestrial plant growth were indicated at concentrations ranging from 1 to 300 mg Cd/kg soil. No effects were indicated in the range of 1 to 56 mg Cd/kg soil (Efroymson et al., 1997a).

IV. Bioaccumulation Potential

Freshwater Ecosystems

Although the bioaccumulation of cadmium is apparent in all aquatic trophic levels, several lines of evidence indicate that cadmium accumulates mostly at lower trophic levels (Cd^{2+}) (Eisler, 1985). In a freshwater food chain model starting from daphnids to fish using the algae *Chlorella vulgaris* as the source of cadmium, Ferard et al (1983) showed that although cadmium did transfer from daphnid to fish, most of the cadmium remained in algae and daphnids. In other experiments where accumulation of cadmium was tested individually for each organism, bioconcentration factors (BCFs) generally decreased at higher trophic levels: algae (2,550), insects (164 to 2200), and fish (200 to 380) (Eisler, 1985a; Ferard et al., 1983; and Kumada et al., 1980). Biomagnification of cadmium is unlikely; however, bioconcentration and limited bioaccumulation may occur at lower trophic levels. No data on sediment accumulation have been identified.

To predict food chain exposures to piscivorous mammals and birds, BCFs of 380, 245, and 200 (L water/kg tissue) from Kumada et al. (1973) were used to arrive at the geometric mean of 265 (Cd^{2+}) . BCFs were based on measured whole-body tissue concentrations in rainbow trout after 30 weeks of exposure. This BCF was used for estimating food chain exposures to piscivorous mammals and birds. Because a more recent study on the pharmacokinetics of cadmium adsorption suggests that it takes about 30 weeks of exposure to reach a 90% of steady-state concentration of cadmium in rainbow trout (Harrison and Klaverkamp, 1989), bioconcentration studies conducted for less than 30 weeks of exposure (Williams and Giesy, 1978; Kumada et al.1980; and Harrison and Klaverkamp, 1989) were not used. Confidence in this BCF value is high because the BCF of 265 is in close agreement with that of an estimated value for rainbow trout of 161 (Harrison and Klaverkamp, 1989)

Terrestrial Ecosystems

Bioaccumulation in terrestrial invertebrates, plants, and small mammals is currently being investigated at Oak Ridge National Labs. Bioaccumulation and bioconcentration factors (BAFs and BCFs) for terrestrial plants, invertebrates, and small mammals have been proposed from review of primary literature sources. The 90th percentile of the bioaccumulation data for these receptors derived from both laboratory and field studies were used to determine terrestrial food chain exposures. For earthworms, a BAF of 41 was proposed for cadmium based on 226 data points. For terrestrial plants, an BCF of 4.6 was proposed based on 289 data points. For small mammals, based on 99 reported values assessing the transfer of cadmium from soil to small mammals, a BAF of 4.0 was proposed (Sample et al., 1997; Samples et al., 1998). These values were used to model food chain exposures to terrestrial species for this analysis, because currently, they stand as the most comprehensive collection of bioaccumulation data for terrestrial ecological receptors (Sample et al., 1997; 1998a; 1998b).

V. CSCL Development

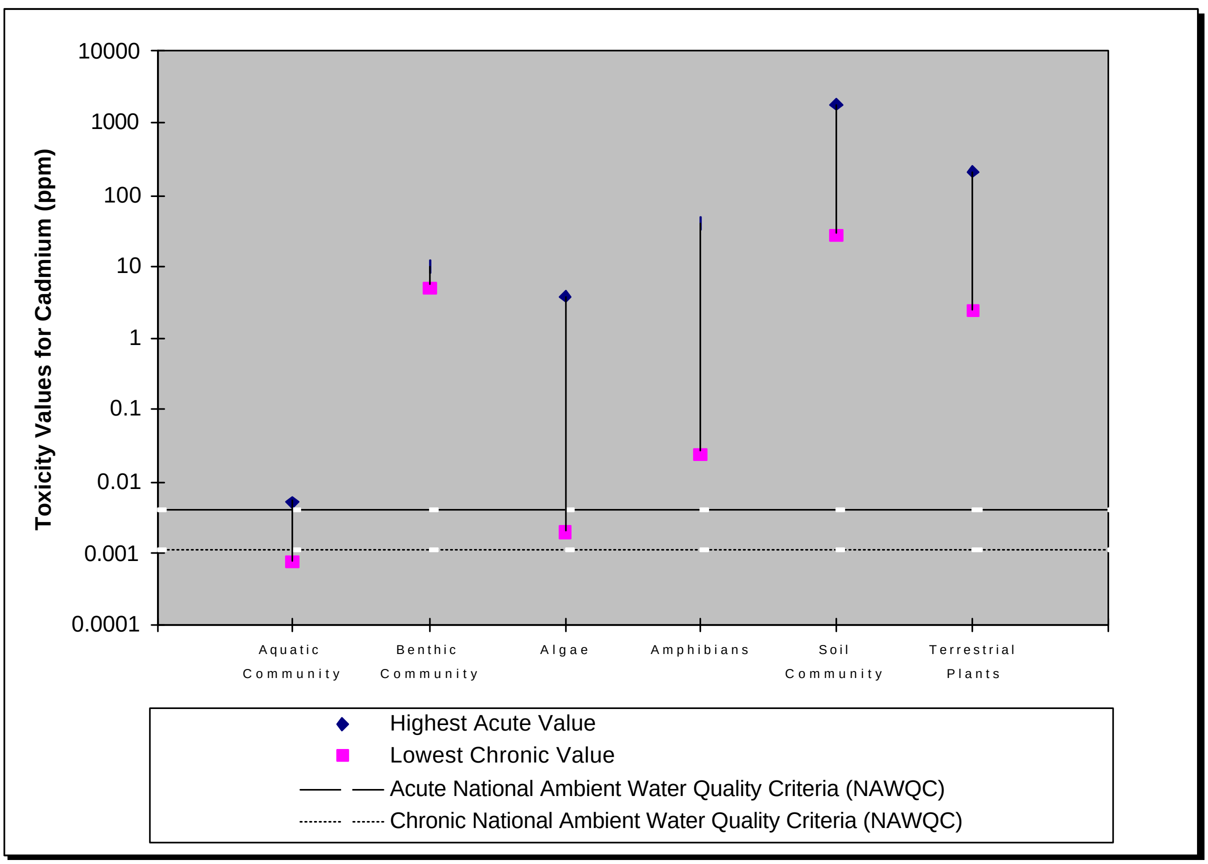

Figure 5: Cadmium: Effects Ranges for Ecological Receptors

The benchmark values presented in this section for mammals and birds were used to derive protective media-specific CSCLs as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor, and predicting the potential bioconcentration in prey, a protective concentration (i.e., CSCL) in soil, sediment, plant tissue or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. It is assumed that by protecting the more sensitive species, the other receptors are protected as well.

Mammals: Numerous studies were identified on the effects of cadmium toxicity to mammalian species. Sutou et al. (1980) assessed cadmium toxicity in rats exposed to 0.1, 1.0 and 10 mg/kg-day over a period of six weeks, including a three-week mating period and up to day 20 of gestation. None of the measured variables showed significant changes in the groups exposed to 0.1 and 1.0 mg/kg-day, however, at 10 mg/kg-day, the number of embryonic implantations and live fetuses decreased significantly. In addition, surviving fetuses from the 10 mg/kg-day treatment group exhibited decreases in body weight, body length and tail length as well as delayed ossification of the vertebrae. These results suggest a NOAEL of 1.0 mg/kg-day and a LOAEL of 10 mg/kg-day for developmental effects. The NOAEL of 1.0 mg/kg-d from the Sutou et al. (1980) study was chosen to derive the mammalian toxicological benchmarks because it contained sufficient dose-response information and focused on developmental endpoints at a critical life stage.

In a study by Loeser and Lorke (1977), dogs given food containing cadmium at doses of 0.02, 0.06, 0.2, and 0.6 mg/kg-day for a 3 month period exhibited no behavioral or developmental effects. From this study, a NOEL of 0.6 mg/kg-day was inferred for dog exposure to cadmium. Sorell and Graziano (1990) exposed female rats to cadmium via drinking water at doses of 5, 50, and 100 ppm on gestation days 6 through 20. Growth retardation, as expressed in decreased fetal and maternal weights, was noted at the two higher doses. Based on the suggested body weight of 0.35 kg and water consumption of 0.046 l/day for Sprague-Dawley rats (U.S. EPA, 1988a), a NOAEL of 0.66 mg/kg-day and a LOAEL of 6.6 mg/kg-day were calculated for developmental effects. With respect to population sustainability, the decreased fetal body weight observed by Sorell and Graziano et al. (1990) was not as significant as the decreased embryonic implantations and live fetuses reported by Sutou et al. (1980). Although dogs are members of the same taxonomic order (Carnivora) as the representative species, the Loeser and Lorke (1977) study does not provide clear dose-response information. While the studies by Sorell and Graziano et al. (1990) and Loeser and Lorke (1977) were not chosen for the development of a toxicological benchmark, they do illustrate the dose range at which cadmium toxicity occurs.

Birds: In one study, dietary cadmium was given to mallard duck hens at 0, 2.0, and 20, and 200 mg/kg for up to 90 days (White & Finley, 1978). No effects in egg laying were seen at the lower dose levels, however, egg production was suppressed in the group given 200 mg/kg. Based on these results a LOAEL of 14.38 mg/kg-day and a NOAEL of 1.43 mg/kg-day can be inferred for reproductive effects.

The NOAEL from the White and Finley (1978) study was selected to derive the toxicological benchmark because: (1) doses were administered over a chronic duration and via oral ingestion, an ecologically significant exposure pathway; (2) the study focused on reproductive toxicity as a critical endpoint; and (3) it contained adequate dose-response information.

The effects on avoidance response to fright stimuli were assessed in one-week-old black ducks fed 4 or 40 ppm cadmium (Heinz et al., 1983). No information on daily food consumption rates were provided; therefore, the use of an allometric equation was required to convert the doses from dietary ppm to mg/kg-day (Nagy, 1987):

$$\textit{Food consumption (kg/day)} = 0.0582(W^{0.651})$$

where W is body weight in kg. Assuming a body weight of 0.053 kg, doses for this study were calculated as 0.1 and 1 mg/kg-day. Ducklings fed 0.1 mg/kg-day ran longer distances away from a fright stimulus than the control group or the 1 mg/kg-day ppm group. The authors could not explain why effects were seen at the lower dose level and not at 1 mg/kg-day. Richardson et al. (1974) investigated the effects of cadmium on Japanese Quail given an oral dose of approximately 75 mg/kg-diet from hatching until 4 or 6 weeks of age. Because daily food consumption was not described, the allometric equation presented above was used to convert the cadmium dose to mg/kg-day. Using a body weight of 0.08 kg, the dietary dose was estimated at 10.5 mg/kg-day. After 4 weeks of exposure, the quail exhibited signs of testicular hypoplasia, growth retardation and severe anemia and after 6 weeks of exposure both heart ventricles were hypertrophied. The studies described demonstrate effects that could impair the survival of a wildlife population. However, the study by Richardson et al. (1974) was not considered suitable for derivation of a benchmark value because of insufficient dose response information. Because behavioral effects were observed at the lower dose and not at the higher dose, the Heinz et al. (1983) study also did not establish a clear dose response relationship.

Data were available on the reproductive and developmental effects of cadmium, as well as on behavioral effects potentially effecting survival. Laboratory experiments of similar types were not conducted on a range of avian species and as such, inter-species differences among wildlife species were not identifiable. There were no other values in the data set which were lower than the benchmark value. Additional avian toxicity data were not identified for birds representing the terrestrial ecosystem therefore, the White and Finley (1978) study on reproductive effects in mallards used in the freshwater ecosystem was also used to calculate a benchmark value.

Freshwater Community: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria (NAWQC) published by the EPA Office of Water. The FCV of 2.5E-03 mg/L for cadmium developed under the GLWQI was selected as the appropriate criteria to use in this analysis. The GLWQI value was considered preferable to the NAWQC because: (1) the GLWQI value is based on the same methodology used to develop NAWQC (i.e., Stephan et al., 1985); (2) the NAWQC data set was augmented with previously unavailable acute and chronic toxicity data; and (3) species taxa used to generate the GLWQI values are suitable for national application since they include species and taxa found throughout the United States. It should be noted that the toxicity of cadmium is hardness dependent and, therefore, the FCV (in µg/L) was calculated using the following equation (US EPA, 1995a), assuming a water hardness of 100 mg/L as calcium carbonate ($CaCO_3$):

$$e^{0.7852(\ln \text{hardness}) - 2.715}$$

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metal concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). Consequently, the FCV for cadmium was adjusted to provide dissolved concentrations as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). The cadmium FCV was adjusted using a conversion factor (CF) of 0.909 for chronic effects to give a dissolved surface water CSCL of 2.3E-03 mg/L. This adjustment reflects the current Agency position on criteria development and regulatory application of metals; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). For example, the relationship between water characteristics (e.g., dissolved organic matter), copper bioavailability, and toxicity has been investigated in some detail (e.g., Allen and Hansen, 1996). For completeness, the total and dissolved surface water CSCLs are presented in Table 1.

<u>Amphibians:</u> No suitable subchronic or chronic studies to develop a CSCL were identified which studied the effects of cadmium exposure on reproductive or developmental endpoints in amphibian species. The variability between experimental designs and test endpoints made consistent comparisons between chronic data prohibitive; however, both acute and chronic data were identified to characterize the toxicity of cadmium to amphibian species. Acute impacts (LC_{50}s) to amphibian species are observed between 0.5 to 0.9 mg Cd/L (as Cd^{2+}) whereas chronic ecotoxicity data range from 0.04 to 0.2 mg Cd/L (Cd^{2+}) (U.S. EPA, 1996). Toxicity endpoints in tests varied from lethality to developing abnormalities. Thirteen different species of amphibians are represented in these effects ranges. The observation that some chronic amphibian data fall below the NAWQC (i.e., 0.0039 mg Cd/L) indicates that amphibians are very sensitive to cadmium exposure. Given the inconsistency in reported chronic data, a CSCL of 1.9 mg cadmium/L was derived based on acute toxicity (Power et al., 1989; U.S. EPA, 1996). Since the CSCL is based on acute data (i.e., lethality), the severity of the potential adverse effects that this CSCL indicates should be noted. Incorporating the amphibian data into the NAWQC within the data requirement categories is currently under consideration. Since amphibian species are more likely to breed in standing waters such as wetlands, ponds, or temporary puddles the appropriateness of combining protection of amphibian receptors with the aquatic community is unclear.

<u>Aquatic Plants and Algae</u>: The toxicological CSCLs for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or (2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). The aquatic plant CSCL for cadmium is 2E-03 mg/L based on reduced population growth rate of *Asterionella formosa* (Suter and Tsao, 1996). Low confidence is placed in this CSCL since it is only based on one study.

<u>Benthic Community</u>- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, CSCLs are developed estimating the 10th percentile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). These values are not NOAA standards; rather, they are used to rank sites based on the potential for adverse ecological effects. A second CSCL document evaluated for sediment CSCL development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also

based on the NOAA data; however, the method of derivation of the criteria was changed. FDEP calculated the criteria (i.e., threshold effects level, TEL) from the geometric mean of the 50th percentile of no effects data and the 15th percentile of the low effects data. The NOAA data, used in both documents, is based on total metal concentrations in sediments, and the toxicity endpoints were measured on species of amphipods, arthropods, and bivalves in addition to a variety of community-based endpoints (e.g., abundance, mortality, species composition, species richness). The FDEP criteria was chosen above the NOAA criteria for the following reasons; (1) the same database was used for both the NOAA criteria and the FDEP criteria development only different derivation methods were used; (2) in most cases, the FDEP criteria was more conservative than the NOAA criteria because a larger portion of the low effects data was used in CSCL development; (3) the marine TEL developed by the FDEP were found to be analogous to TELs observed in freshwater organisms (Smith et al., 1995).

The CSCL for cadmium was derived from 433 toxicity data points for low and no effects levels. For the screening level analysis of cadmium, the TEL of 6.8E-01 mg cadmium/kg sediment was selected as an appropriate sediment CSCL. Based on the quality and quantity of cadmium sediment data, the degree of confidence in the TEL value for cadmium was considered high (MacDonald, 1994).

Terrestrial Plants: Adverse effects levels for terrestrial plants were identified for endpoints ranging from percent yield to root length. As presented in Efroymson et al. (1997a), phytotoxicity CSCLs were selected by rank ordering the LOEC values and then approximating the 10th percentile. If there were 10 or fewer values for a chemical, the lowest LOEC was used. If there were more than 10 values, the 10th percentile LOEC was used. Such LOECs applied to reductions in plant growth, yield reductions, reduction in seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. The selected CSCL for phytotoxic effects of cadmium in soils is 4.0 mg cadmium/kg soil (Efroymson et al., 1997a). The derivation of the CSCL is based on 81 phytotoxicity data points on various agricultural (e.g., barley, ryegrass) and silverculture (e.g., spruce) species measuring growth endpoints such as height and weight of shoots and roots, yield, and germination success. Considering this CSCL was based on multiple studies over a range of species, confidence in this CSCL is high.

Soil Community: CSCLs for soil from community-based effects presented in Hazardous Waste Identification Rule (RTI, 1995b) of 1 mg/kg was proposed for cadmium. This value developed from various different soil-based organisms may be more appropriate than CSCLs which are based on single soil species such as earthworms. Calculation of the CSCL involves incorporating the no observed effects concentration (NOEC) and lowest observed effects concentration (LOEC) data set for soil biota and to a statistically derived formulation designed to protect 95% of the species potentially present in soil. The CSCL proposed herein will provide long-term sustainability of a functioning soil community for multiple uses of the affected area, such as agriculture and residential use (RTI, 1995b). Because 7 studies were used to derive this value, confidence in this CSCL is moderate.

As an aside, although the soil CSCL for cadmium falls below the background concentration in the southeastern region, it may still be adequate for use nationally because confidence in the background concentration of cadmium, based on only 12 samples, is low (typical sample size is between 300 to 1200). In addition, background concentrations of cadmium vary among by regions. For example, the average background concentration of cadmium is 0.22 mg/kg in Oak Ridge Reservation, TN (Efroymson et al., 1997b); and Alloway(1995) presents background concentration ranging from 0.01 to 2.0 mg/kg (sample size unknown); all are below the CSCL. Additionally, if the background concentrations were categorized by soil type, the typical range is between 0.37 to 0.78 mg/kg soil. Confidence in background soil concentration is low and the cadmium soil CSCL is likely to be adequate most of the time.

Table 1. Cadmium CSCL in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Mammals	1.1E-02	mg/L water	Food web	River Otter	Sutou et al., 1990
Birds	1.9E-02	mg/L water	Food web	Kingfisher	White and Finley, 1976
Algae and Aquatic Plants	2.0E-03	mg/L water	Direct contact	*Asterionella formosa*	Suter and Tsao, 1996
Freshwater Community					
Total	2.5E-03	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1995b
Dissolved	2.3E-03	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1995b; 60FR22229
Benthic Community	6.8E-01	mg/kg sediment	Direct contact	Benthos	MacDonald, 1994
Amphibian (acute effects)	1.9E+00	mg/L water	Direct contact	Various amphibian species	Power et al., 1989; U.S. EPA, 1996
Terrestrial					
Mammals	1.4E+00	mg/kg soil	Food web	Meadow vole	Sutou et al., 1990
Birds	1.6E+00	mg/kg soil	Food web	American woodcock	White and Finley, 1976
Mammals	5.5E+00	mg/kg plant tissue	Food web	Meadow vole	Sutou et al., 1990
Birds	3.7E+01	mg/kg plant tissue	Food web	Northern bobwhite	White and Finley, 1976
Plant Community	4.0E+00	mg/kg soil	Direct contact	Plants (unspecified species)	Efroymson et al., 1997a
Soil Community	1.0E+00	mg/kg soil	Direct contact	Soil invertebrates	RTI, 1995b

Ecotoxicological Profile for Ecological Receptors
Chromium

This ecotoxicological profile on chromium contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (5) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of chromium so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

Chromium is a naturally occurring metallic element. Background concentrations in soils throughout the United States range from 1.0 to 2,000 ppm, with a mean value of 54 ppm (Dragun and Chiasson, 1991). It is estimated that 32,000 tons/yr of chromium are naturally mobilized by weathering (Outridge and Scheuhammer, 1993). A considerably greater amount, however, is released to the environment as the result of anthropogenic activities (Eisler, 1986a).

Chromium may exist in multiple oxidation states, ranging from Cr^{2-} to $Cr^{6+,}$, the trivalent and hexavalent forms being the most biologically significant. The trivalent form, Cr^{3+}, is the predominant naturally-occurring form, and is an essential micronutrient in animals, though not essential for plants (Will and Suter, 1994). Deleterious effects, however, such as teratogenesis and decreased sperm counts, have been associated with Cr^{3+} exposures (Diaz-Mayans et al, 1986, Zahid et al., 1990). Chromium in the hexavalent, Cr^{6+}, form is more soluble and bioavailable than other forms, and is generally considered to be its primary toxic form. About 40% of bioavailable chromium exists as Cr^{6+} (ATSDR, 1993h). $Chromium^{6+}$ may induce mutagenic, carcinogenic, and teratogenic effects (Eisler, 1986a). Chromium's chemical form in the environment may be affected by both abiotic, physico-chemical conditions and biotic cycling processes.

II. Geochemistry of Chromium in Various Ecological Media

Chromium in Soils

- Cr^{3+} is the dominant chromium species in soils.
- Cr^{6+} occurs as $HCrO_4^-$, CrO_4^{2-}, or $Cr_2O_7^{2-}$ in soils.
- The solubility of Cr^{3+} is low within the pH range of most soils.
- Reduction-oxidation, precipitation-dissolution, adsorption-desorption mechanisms usually control chromium biogeochemistry in soils.

Trivalent chromium, Cr^{3+}, and hexavalent chromium, Cr^{6+}, can exist in soils. However, chromium occurs predominantly in the trivalent state in soils (as insoluble $Cr_2O_3 \cdot H_2O$) (EPA, 1989a, cited in ATSDR, 1993). Forms of Cr^{6+} are the chromate ion, $HCrO_4^-$ predominant at pH<6.5, or CrO_4^{2-}, predominant at pH> 6.5, and as dichromate, $Cr_2O_7^{2-}$ predominant at higher concentrations (>10mM) and at pH 2-6 (McLean and Bledsoe, 1992). The total concentration of chromium in unpolluted soils ranges from ~30-300 µg/g (Katz and Salem, 1994). Smith et al. (1989, cited in Katz and Salem, 1994) report background concentrations of 57 Fg/g for U.S. soils. Concentrations of Cr^{6+} greater than a few tenths of a ppb in soils probably indicate anthropogenic contamination (Katz and Salem, 1994).

Transport of chromium within soils is influenced by factors such as pH, ion exchange capacity and interstitial pore size (Katz and Salem, 1994). The processes controlling the fate and transport of chromium species in soils are complex and interrelated. More detailed reviews of the biogeochemistry of chromium in soils are found elsewhere (e.g., Bartlett and James, 1989; Katz and Salem, 1994). The anionic nature of Cr^{6+} limits its association with soil surfaces to positively charged exchange sites, which decrease in number as the soil pH increases (McLean and Bledsoe, 1992). Hexavalent chromium can be reduced to Cr^{3+} under normal soil pH and redox conditions. Smith et al. (1989, cited in Katz and Salem, 1994) reported a high positive reduction potential for Cr^{6+} and proposed that, in the presence of organic matter, Cr^{6+} was readily reduced to Cr^{3+}. Moreover, they acknowledged that the reduction was pH dependent, and suggested that the hydrated Cr^{3+} oxides formed were immobilized through their incorporation into iron oxides in the soil.

Bartlett and James (1979, cited in Katz and Salem, 1994) showed that Cr^{3+} was oxidized to Cr^{6+} in fresh soil samples. Manganese oxides were the electron link between the Cr^{3+}/Cr^{6+} redox couple and atmospheric oxygen. The surface characteristics of the manganese oxides and Cr^{3+} transport to those surfaces controlled its oxidation. The oxidation of Cr^{3+} was favored by its speciation and mobility in the soil and by the age of the Mn^{6+} oxide surface and its freedom from adsorbed, reduced organic matter, and Mn^{2+} (Katz and Salem, 1994). Rai et al. (1989, cited in Katz and Salem, 1994) identified oxidation-reduction, precipitation-dissolution, and adsorption-desorption as mechanisms controlling the biogeochemistry of chromium. $Iron^{2+}$, S^{2-}, and organic matter in soil were important potential reductants for Cr^{6+}, and manganese dioxide was considered important for the oxidation of Cr^{3+} to Cr^{6+}. The solubility of Cr^{3+} was very low within the pH range of most soils (Rai et al.,1989, cited in Katz and Salem, 1994).

Chromium in Surface Waters

! The chromium species Cr^{3+} and Cr^{6+} are found in surface waters.
! Cr^{3+} occurs more often in a particulate phase than does Cr^{6+}.
! In sea water Cr^{6+} is the dominant species in the dissolved phase, but kinetic effects mean that significant quantities of Cr^{3+} can also be present.

Chromium concentrations in U.S. river water are typically <1 to 30 Fg/l (ATSDR, 1993 and references therein). In lake water, chromium concentrations are typically 5 Fg/l or lower (Borg, 1987; Cary, 1982, cited in ATSDR, 1993). Bart and von Gunten (1979, cited in Katz and Salem, 1994) reported that chromium was transported predominantly as solids in the River Aare. Pettine et al. (1992, cited in Katz and Salem, 1994) determined that chromium in the Po River (Italy) was partitioned between particulate (~90%) and dissolved (~10%) phases. Of the dissolved phase, at least 85% was hexavalent chromium. Pettine et al. (1992, cited in Katz and Salem, 1994) proposed that the dissolved chromium underwent a redox cycle involving hydrogen peroxide and Fe^{2+}, with subsequent incorporation of the Cr^{3+} into a particulate phase prior to sedimentation. Photoreduction has been invoked as a mechanism for the reduction of Cr^{6+} to Cr^{3+} (e.g., Kieber and Heiz, 1992; Kaczynski and Kieber, 1993, cited in Katz and Salem, 1994). Their mechanism involves solar radiation induced reduction of Fe^{3+} to Fe^{2+}, together with the oxidation of organic matter adsorbed onto the particulate hydrated Fe^{3+} oxide and subsequent reduction of Cr^{6+} by the Fe^{2+}. The Cr^{3+} formed is then "scavenged by $Fe(OH)_3$ colloids formed simultaneously" (Kieber and Heiz, 1992, cited in Katz and Salem, 1994) and incorporated into riverine sediments.

Chromium in Sediments

> ! Most sedimentary Cr is in aluminosilicate phases.
> ! Regeneration of sedimentary Cr leads to increased dissolved Cr concentrations above the sediment-water interface.

Chromium concentrations in marine sediments are typically 60-100 ppm, which is similar to those of crustal rock and reflects the lithogenic nature of chromium (Mayer, 1988). In addition, partitioning studies tend to show most sedimentary chromium in aluminosilicate phases (Loring, 1979; Mayer and Fink, 1980, cited in Mayer, 1988). Very little information was available on the diagenesis of sedimentary chromium, however, evidence from a few depth profiles suggests little redistribution of chromium due to diagenetic processes (Kato et al., 1983; Kahn et al., 1984, cited in Mayer, 1988).

Dissolved chromium concentrations commonly increase just above the sediment-water interface as chromium is regenerated from sediments into the overlying water column (Mayer, 1988). Two processes are suggested for the remobilization of chromium from marine sediments into the overlying water column (Mayer, 1988 and references therein): dissolution of biogenic material at the sediment-water interface (particularly for siliceous tests which contain 8 ppm Cr); and, catalytic oxidation of sedimentary Cr^{3+} by manganese dioxide, which leads to remobilization of highly soluble hexavalent chromium. Remobilization of chromium from near shore sediments may be more intensive than from deep sediments because of the higher Cr content of near shore sediment pore water (Douglas et al., 1986; Kahn et al., 1983, cited in Mayer, 1988) and higher irrigation rates.

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystem

For aquatic biota, mobility and overall toxicity of chromium is affected by abiotic variables like water hardness, temperature, and pH, in addition to biotic variables such as species sensitivity and age (Eisler, 1986a). $Chromium^{6+}$ is expected to be more toxic to juvenile species in soft, acidic waters. Waterborne pathways contribute more to aquatic exposure than do food-chain based pathways. Chromium's toxicity in fish results in interference of oxygen transfer across the gills (Na_2CrO_4; $CrO_4^{\ 2-}$) (Van der Putte and Part, 1982).

Aquatic biota may be affected by chromium toxicity. Sublethal effects include abnormal enzyme activity, altered blood chemistry, behavior changes, disruption of osmoregulation, and inhibition of photosynthesis (Eisler, 1986a). Freshwater fish and invertebrates exhibit reduced survival and growth at ambient water concentrations as low as 10 to 16 µg/L (Outridge and Scheuhammer, 1993). Algal growth may be inhibited at exposures of 10 ppb (Eisler, 1986a). Amphibian receptors demonstrate acute toxicity (LC_{50}s) in the range of 0.03 to 100 mg/L from exposure durations of less than 8 days. Extended exposures of *Xenopus laevis* to chromium (i.e., 100 days) indicated no effects to mortality, development, and growth between 1 to 3.2 mg/L (U.S. EPA, 1996). Considering the overlap in ranges of acute and chronic effects indicates that some species of amphibians appear more tolerant than others. American black ducks exposed during a field study to dietary chromium (10 µg/g body weight) for 10 weeks exhibited altered blood chemistry and growth, decreased survival rates, but showed no change in reproductive success (chemical form unspecified) (Custer et al., 1986).

Terrestrial Ecosystems

Acute toxicity (50 - 100% mortality) resulted from oral ingestion (10-70 mg/kg body-weight) of chromium^{6+} in animals. Death from acute chromium exposures is generally attributed to kidney failure although impacts on the immune system have been noted as well (Outridge and Scheuhammer, 1993). Neurological impairment has been noted at doses of 102.1 mg/kg/day (oral exposure) in rats (Diaz-Mayans et al., 1986). Sublethal chromium toxicity in mammals, as a result of oral doses of chromium^{6+}, may be characterized by systemic effects (e.g., tissue damage) (Outridge and Scheuhammer, 1993).

Chromium^{6+} may also impact reproductive viability in both mammals and birds. Pregnant, female albino mice given chromium^{6+}, as potassium dichromate, via drinking water showed an increase in fetal resorption as well as pre and post implantation losses at doses of greater than 250 ppm (Trivedi et al., 1989). Doses of 33 mg/kg/day in mice have been reported to reduce sperm count and result in the degeneration of the seminiferous tubules (Zahid et al., 1990).

Once taken up into biota, hexavalent chromium is immediately reduced to trivalent chromium, making distinction of biological effects difficult (Zahid, et al. 1990). Additionally, it has been suggested that although chromium^{6+} has a high potential for biological interaction, only a small fraction of available chromium^{6+} is assimilated by exposed biota thereby reducing toxicity (Eisler, 1986a).

Impacts to other terrestrial receptors have not been well characterized. Plants generally contain the majority of the biologically active chromium in the aquatic environment (Outridge and Scheuhammer, 1993). The implications of this for food chain exposures is uncertain. In addition, worm reproduction was inhibited at 12.5 ppb (Eisler, 1986a); however, no other studies were identified to determine impacts to the soil community.

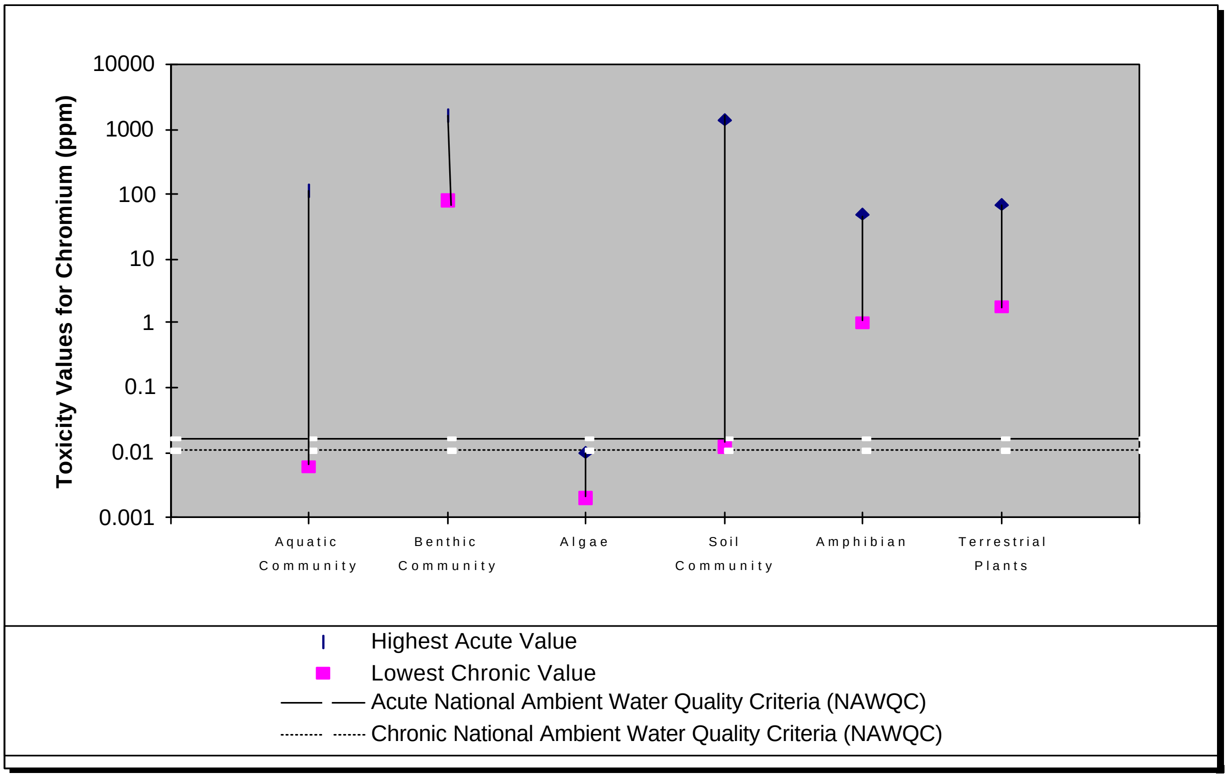

Figure 6: Chromium: Effect Ranges for Ecological Receptors

IV. Bioaccumulation Potential

Freshwater Ecosystems

Toxic effects attributable to the bioaccumulation of chromium within the food chain are expected to be minimal (Eisler, 1986a). Although chromium may accumulate to toxic levels in some receptors, most organisms die before accumulating levels of chromium potentially toxic to a predator. Biomagnification is thus unlikely to occur. As with some other metals, chromium concentrations in biota have been noted to decrease with increasing trophic level (Outridge and Scheuhammer, 1993). Bioconcentration factors (BCFs) of 0.13 (L/kg) and 2.8 (L/kg) cited by Stephan (1993) in the form of Cr6+ were used to arrive at a geometric mean of 0.60. Because whole-body BCFs are not available, the measured BCFs of muscle of rainbow trout (*Salmo gairdneri*) is used. Insufficient data were identified to determine a BCF value for other aquatic organisms.

Terrestrial Ecosystems

Bioaccumulation in terrestrial invertebrates, plants, and small mammals is currently being investigated at Oak Ridge National Labs. Bioaccumulation and bioconcentration factors (BAFs and BCFs) for terrestrial plants, invertebrates, and small mammals have been proposed from review of primary literature sources. The 90th percentile of the bioaccumulation data for these receptors derived from both laboratory and field studies were used to determine terrestrial food chain exposures. For earthworms, a BAF of 3.2 was proposed for chromium based on 67 data points. For terrestrial plant there was no was BCF proposed. For small mammals, based on 38 reported values assessing the transfer of chromium from soil to small mammals, a BAF of 0.33 was proposed (Sample et al., 1997; Samples et al., 1998). These values were used to model food chain exposures to terrestrial species for this analysis, because currently, they stand as the most comprehensive collection of bioaccumulation data for terrestrial ecological receptors (Sample et al., 1997; 1998a; 1998b).

V. CSCL Development

The benchmark values presented in this section for mammals and birds were used to derive protective media-specific CSCLs as outlined in the stressor response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor, and the potential bioconcentration in prey, a protective concentration (i.e., CSCLs) in soil or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. By protecting, the more sensitive species, protection to other receptors is assumed.

Mammals: Several studies were identified which investigated the effects of chromium^{6+} exposure in mammals. Zahid et al. (1990) fed male mice potassium dichromate in feed at doses of 100, 200 and 400 ppm. After 7 weeks of treatment, the group receiving 100 ppm exhibited reduced sperm counts and degeneration of the outer cellular layer of seminiferous tubules. Morphologically altered sperm were seen in the rats receiving 200 ppm sodium dichromate. To convert to a daily dose value, the 100 ppm concentration was multiplied by the reported food consumption per animal (0.0075 kg/day) and divided by an average of the reported mice body weights (0.023 kg). A LOAEL of 33 mg/kg-day resulted for reproductive effects. Because the Zahid et al. (1990) study considered reproductive effects, illustrated a clear dose-response relationship and represents the lowest LOAEL identified for reproductive effects, it was chosen for the derivation of a CSCL value. The selected study LOAEL, 33 mg/kg-day, was divided by 10 to provide a conservative LOAEL-to-NOAEL safety factor.

Other benchmark studies for mammals were identified and evaluated for CSCL development. Trivedi et al. (1989) administered 250, 500 and 1000 ppm Cr^{6+} as potassium dichromate in drinking water to female mice during gestation days 1 through 19. Mice given the lowest dose, 250 ppm, exhibited greater incidences of resorption and post-implantation losses, resulting in a LOAEL for reproductive effects of 250 ppm. To convert this value to a daily dose in units of mg/kg-day, an allometric equation for water consumption for laboratory mammals was used (U.S. EPA, 1988a)

$$\textit{Water Consumption (L/day)} = 0.10(W^{0.7377)}$$

where W is body weight in kilograms. Using the reported body of weight 0.03 kg and a calculated daily water consumption of 0.008 L/day, the ppm dose was converted to a daily dose LOAEL of 67 mg/kg-day. In another study (Diaz-Mayans et al., 1986), rats were given chromium^{6+} as sodium chromate in drinking water at dosage levels of 70 mg/L and 700 mg/L. After 28 days decreases in motor activity and balance were seen in the group receiving 700 mg/L. No adverse effects on motor activity were exhibited by the treatment group receiving 70 mg/L. This implies a NOAEL of 70 mg/L and a LOAEL of 700 mg/L for neurological effects. The mg/L doses were converted to daily doses through the use of the allometric equation (U.S. EPA, 1988a) presented above. Based on the reported body weight of 0.24 kg, the water consumption rate was estimated as being 0.03 L/day. This resulted in an estimated NOAEL of 8.8 mg/kg-day and an estimated LOAEL of 88 mg/kg-day. The Trivedi et al. (1989) study was not chosen for the development of a mammalian benchmark because the derived LOAEL was not the lowest value in the data set and would therefore not be appropriate as the benchmark value. The Diaz-Mayans et al. (1986) study was not selected because it focused on neurological impairment as the primary endpoint rather than reproductive or developmental endpoints.

It is expected that the selection of toxicity studies utilizing chromium^{6+} will provide a conservative basis for benchmark development for waterborne pathways. However, uncertainty regarding the impact of variable and interchanging oxidation states and chemical forms may confound the interpretation of toxic effect. It should be noted that the use of a chromium^{6+} benchmark to model pathways involving the consumption of metabolized chromium (e.g., chromium in animals or plants that have been exposed to chromium^{6+} and then converted it to chromium) may be inappropriate.

__Birds__: Study done by Haseltine et al., unpubl. data (as cited by Sample et al., 1996) were used to derive CSCLs for birds. They examined chromium's effects on the reproduction of black duck with a diet of 10 and 50 ppm. Ducklings treated with 50 ppm exhibited mortality. Because the study was conducted during a critical growth period, a NOAEL of 10 ppm and a LOAEL of 50 ppm can be inferred for developmental effects. As reported by Sample et al. (1996), the NOAEL for duckling is 1 mg/kg-day and the LOAEL is 5 mg/kg-day. Additional avian toxicity data were not identified for birds representing the terrestrial ecosystem. Therefore, the study used for freshwater ecosystem was also used to calculate terrestrial avian CSCLs values.

__Freshwater Community__: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria (NAWQC) published by the EPA Office of Water. The FCV of 8.6E-02 mg/L for chromium^{3+} and the FCV of 1.1E-02 mg/L for chromium VI developed under the GLWQI were selected as the appropriate criteria to use in this analysis. The GLWQI values were considered preferable to the NAWQC because: (1) the GLWQI values are based on the same methodology used to develop NAWQC (i.e., Stephan et al., 1985); (2) the NAWQC data set was augmented with previously unavailable acute and chronic toxicity data; and (3) species taxa used to generate the GLWQI values are suitable for national application since they include species and taxa found throughout the United States. The toxicity of chromium^{3+} is hardness dependent; therefore, the FCV (in µg/L) was calculated using the following equation (U.S. EPA, 1995a), assuming a water hardness of 100 mg/L as calcium carbonate ($CaCO_3$):

$$e^{0.819(\ln \text{hardness}) + 0.6848}$$

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metals concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). Consequently, the FCV for chromium^{3+} and chromium^{6+} were adjusted to provide dissolved concentrations as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). The chromium^{3+} FCV was adjusted using a conversion factor (CF) of 0.860 for chronic effects to give a dissolved surface water CSCL of 7.4E-02 mg/L. The chromium^{6+} FCV was adjusted using a CF of 0.962 to yield a dissolved surface water CSCL of 1.1E-02 mg/L. This adjustment reflects the current Agency position on criteria development and regulatory application of metals; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). For example, the relationship between water characteristics (e.g., dissolved organic matter), copper bioavailability, and toxicity has been investigated in some detail (e.g., Allen and Hansen, 1996). For completeness, the total and dissolved surface water CSCLs are presented in Table 1.

Amphibians: No suitable subchronic or chronic studies were identified which studied the effects of chromium toxicity on reproductive or developmental endpoints in amphibian species; however, several acute studies were identified characterizing chromium toxicity. Review of data collected from six experiments indicate that the acute toxicity of chromium ranges from 0.03 to 100 mg/L, with a geometric mean of 9.8 mg chromium/L. Acute studies were conducted on various amphibian species (i.e., six amphibian species represented) during embryo and tadpole lifestages. Chemical exposures were conducted with chromium trioxide and potassium dichromate. The observation that the lowest acute amphibian value approximates the FAV, of 0.016 mg chromium/L determined for the freshwater community indicates that similar sensitivities are present between species. One chronic study indicated no effects to reproductive and developmental endpoints of developing *Xenopus laevis* tadpoles exposed for 100 days to 3.2 mg chromium/L. Given that minimal chronic data was available, a CSCL of 9.8 mg chromium/L was derived based on acute toxicity. Since the CSCL is based on acute data (i.e., lethality), the severity of the potential adverse effects that this CSCLs indicates should be noted. Investigations are ongoing to review the possibility of incorporating amphibian data into the NAWQC. Since amphibian species are likely to breed in standing waters such as wetlands or ponds, the appropriateness of combining protective levels of amphibian receptors and the freshwater community is unclear at this time (Power et al., 1989; U.S. EPA, 1996).

Benthic Community- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, criteria are developed estimating the 10th percentile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). These values are not NOAA standards; rather, they are used to rank sites based on the potential for adverse ecological effects. A second criteria document evaluated for sediment criteria development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the criteria was changed. FDEP calculated the criteria (i.e., threshold effects level, TEL) from the geometric mean of the 50^{th} percentile of no effects data and the 15^{th} percentile of the low effects data. The NOAA data, used in both documents, is based on total metal concentrations in sediments, and the toxicity endpoints were measured on species of amphipods, arthropods, and bivalves in addition to a variety of community-based endpoints (e.g., abundance, mortality, species composition, species richness). The FDEP criterion was chosen above the NOAA criterion for the following reasons; (1) the same database was used for both the NOAA criteria and the FDEP criteria development only different derivation methods were used; (2) in most cases, the FDEP criterion was more conservative than the NOAA criterion because a larger portion of the low effects data was used in CSCL development; (3) the marine TEL developed by the FDEP were found to be analogous to TELs observed in freshwater organisms (Smith et al., 1995).

The CSCL for chromium was derived from 354 toxicity data points for low and no effects levels. For the screening level analysis of chromium, the TEL of 5.2E+01 mg chromium/kg sediment was selected as an appropriate sediment CSCL. Based on the quality and quantity of chromium sediment data, the degree of confidence in the TEL value for chromium was considered high (MacDonald, 1994).

Algae and Aquatic Plants: The CSCLs for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or (2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). The aquatic plant CSCL for $chromium^{6+}$ is 2 E-03 mg/L based on the incipient inhibition of *Microcystis aeruginosa*. Low confidence is placed in this CSCL since it is only based on one study.

Terrestrial Plants: As presented in Efroymson et al. (1997a), phytotoxicity CSCLs were selected by rank ordering the lowest observable effects concentration (LOEC) values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the CSCL. Such LOECs applied to reductions in plant growth, yield, or seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. The selected CSCL for phytotoxic effects of chromium in soils is 1 mg chromium/kg soil which is based on 7 phytotoxicity studies conducted using primarily agricultural (e.g., lettuce, tomato, oats) species measuring growth endpoints such as shoot weight. Considering this CSCL was based on several studies identifying effects on various species, confidence in this CSCL is moderate (Efroymson et al., 1997a).

Soil Community: CSCLs identified in Efroymson et al. (1997b), all fell below mean background concentrations; therefore, the soil quality guideline of 64 mg/kg soil developed by the Canadian government was proposed. This CSCL was developed as a protective level to ensure that long-term crop development and livestock production could continue on soils demonstrating concentrations at or below the CSCL. Since the methodology was not presented in detail, the specific derivation methods and intrinsic assumptions could not be assessed; therefore, the CSCL should be used with caution.(CCME, 1997).

Table 1. Chromium CSCLs in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Mammals	4.5E+00	mg/L water	Food web	River Otter	Zahid et al., 1990
Birds	4.1E+00	mg/L water	Food web	Kingfisher	Sample et al.,1996
Algae and Aquatic Plants	2.0 E-03	mg/L water	Direct contact	*Microcystis aeruginosa*	Suter and Tsao, 1994
Freshwater Community					
Total (Cr^{3+})	8.6E-02	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1996b
Dissolved (Cr^{3+})	7.4E-02	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1996b; 60FR22229
Total (Cr^{6+})	1.1E-02	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1996b
Dissolved (Cr^{6+})	1.1E-02	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1996b; 60FR22229
Benthic Community	5.2E+01	mg/kg sediment	Direct contact	Benthos	MacDonald, 1994
Amphibians (acute effects)	9.8E+00	mg/L water	Direct contact	Various amphibian species	Power et al., 1989; U.S. EPA, 1996
Terrestrial					
Mammals	1.7E+02	mg/kg soil	Food web	Raccoon	Zahid et al., 1990
Birds	1.9E+01*	mg/kg soil	Food web	American woodcock	Sample et al.,1996
Mammals	8.8E+00	mg/kg plant tissue	Food web	Meadow vole	Zahid et al., 1990
Birds	2.3E+01	mg/kg plant tissue	Food web	Northern bobwhite	Sample et al.,1996
Plant Community	1.0E+00*	mg/kg soil	Direct contact	Soybean, lettuce, tomato, oat	Efroymson et al., 1997a
Soil Community	6.4E+01	mg/kg soil	Direct contact	Soil invertebrates	CCME, 1997

* This CSCL should not be used because it is below soil background concentrations (lowest mean background concentration 37 mg/kg chromium/kg soil). This exceedance may be an artifact of our back-calculation method for avian receptors(i.e., calculating media-specific CSCLs from the benchmark study). Secondly, the CSCLs exceeding for the plant and soil community is probably related to bioavailability. Toxicity experiments in the lab usually expose receptors to a more bioavailable form of the constituent giving a lower toxicity values to base the CSCLs on.

Ecotoxicological Profile for Ecological Receptors
Copper

This ecotoxicological profile on copper contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (5) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of copper so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

Copper is a metallic element, occurring naturally in rock, soil, water, sediment, air, and biota. In aqueous solutions, copper can exist in the +1 and +2 valance states. $Copper^{+}$ predominates in relatively reducing conditions, whereas Cu^{2+} dominates in oxidizing conditions.

Most of the anthropogenic release of copper to the environment is to land (Syracuse Research Corp., 1989). Background concentrations in soils throughout the United States range from less than 1 to 700 ppm, with a mean value of 25 ppm (Dragun and Chiasson, 1991). Near copper production sites, however, concentrations of nearly 7000 ppm have been measured. Copper from wastes is usually in an inert mineral form, and so is largely immobile and unavailable to biota. Most copper in the soil environment is in mineral form or strongly bound to particles, although some soluble copper compounds may become more available for uptake by plants and animals. In water, typical copper concentrations range from 4 to 10 ppb. Free copper ion concentrations are generally very low, as most copper will be strongly adsorbed to organic matter. The free ionic form of copper is much more toxic to aquatic biota than copper which is complexed with dissolved organic matter or with SPM or colloidal matter. Copper is an essential nutrient for all living organisms; however, long-term exposure to elevated levels of copper may have adverse effects, including liver and kidney damage, increased blood pressure, decreased hemoglobin, and decreased survival (Syracuse Research Corp., 1989).

II. Geochemistry of Copper in Various Ecological Media

Copper in Soils

- Most copper is strongly adsorbed in soils.
- Copper binds more strongly in soils than do other divalent cations.
- Organic matter, pH, and ionic strength are key parameters affecting the adsorption of copper in soils.

Most copper (Cu) deposited in soils will be strongly adsorbed and held within the upper few centimeters of the soil (ATSDR, 1989). In general, copper will adsorb to organic matter, carbonate minerals, clays, and hydrous iron-manganese oxides (ATSDR, 1989 and references therein). In most temperate soils, pH, organic matter content, and ionic strength are the key parameters affecting adsorption (ATSDR, 1989 and references therein). Copper binds more strongly to soil than other divalent cations and the distribution of copper in soil solution is less dependent on pH than is that of other metals (ATSDR, 1989 and references therein). Numerous workers have undertaken field and experimental studies to investigate the processes controlling copper speciation in soils (ATSDR, 1989 and references therein). Elliot et al. (1986, cited in ATSDR, 1989) studied pH-sensitivity on Cd, Cu, Pb, and Zn adsorption in mineral and organic-rich soils. They determined that adsorption increased with increasing pH, and that Cu and Pb were more strongly adsorbed than Cd and Zn. Removal of the organic matter from these soils resulted in a decrease in the adsorption of Cu, demonstrating the importance of organic matter in copper adsorption. Similarly, in leaching experiments with mineral and peat (high organic matter) soils, Cu was leached more slowly and in much lower concentrations than Zn, Cd, and Ni (Tyler and McBride, 1982 cited in ATSDR, 1989). Other studies have shown that copper is generally retained within the upper most layers of the soil when applied in either solid (e.g., sludge) or liquid (e.g., waste water effluent) form (ATSDR, 1989 and references therein).

Copper in Surface Waters

- Copper is relatively mobile in the aqueous environment. Copper can exist as the hydrated ion, as inorganic complexes, and as organic complexes in natural waters.
- Cu^{2+}, $Cu(HCO_3)^+$, $Cu(OH)_2$ are major soluble species of copper in natural waters.
- The behavior of copper is strongly controlled by geochemical processes (interaction with dissolved organic matter, association with SPM and colloids). Biological processes have little influence on its behavior.

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In natural waters, copper can exist as the hydrated ion, as inorganic complexes, and as organic complexes. Under oxidizing conditions, Cu^{2+} is the dominant species major soluble copper species within the pH range of natural waters are Cu^{2+}, $Cu(HCO_3)^+$, and $Cu(OH)_2$ (Long and Angino, 1977, cited in ATSDR, 1989). However, within the range of pH and carbonate concentrations of natural waters, most copper exists complexed with carbonate rather than as free Cu^{2+}. Moreover, in most natural waters, biogeochemical processes (e.g. adsorption, complexation) reduce free Cu^{2+} concentrations to very low levels.

In rivers, the behavior of copper is primarily controlled by geochemical processes (Hart and Hines, 1995). Copper behavior is heavily dependent upon the balance between complexation with dissolved organic matter and association with suspended particulate matter (SPM) and colloidal matter. Biological processes have only a minor influence on its behavior.

A survey of nine rivers in the U.K. showed 43-88% of the copper analyzed was in the particulate phase (Stiff, 1971, cited in ATSDR, 1989). Experiments using SPM from the Flint River, Michigan, showed that the fraction of copper adsorbed increased with increasing pH, reaching a maximum at pH 5.5-7.5 (McIlroy et al., 1986, cited in ATSDR, 1989).

The dissolved (< 0.4Fm) phase includes free ionic copper, soluble copper complexes, fine particulates and colloids (which may include hydroxides and complexes with amino acids) (ATSDR, 1989). Different forms of copper are labile (i.e., mobile and bioavailable) to different degrees. For example, free ionic copper is very labile, whereas colloid-bound copper is non-labile (Tan et al., 1988, cited in ATSDR, 1989). Typically, 18-70% of dissolved copper in river water is moderately labile, and 12-30% slowly labile (Tan et al., 1988, cited in ATSDR, 1989) (n.b., the definitions are method-dependent and indicate relative rather than specific behavior).

Both pH and the presence of competing ligands affect the complexation of copper with inorganic and organic ligands. For example, in river water from the northwestern USA with relatively high pH (7.0-8.5) and alkalinity (24-219 ppm as $CaCO_3$), inorganic copper species were dominant at both high and low copper concentrations. Conversely, in lake and river water from Maine with relatively low pH (4.6-6.3) and alkalinity (1-30 ppm as $CaCO_3$), organic-copper complexes were dominant. However, following a period of rainfall which increased the inorganic load of the lakes and rivers (pH and alkalinity increased), inorganic copper complexes became the dominant species present in the water column (Truitt and Weber, 1981, cited in ATSDR, 1989).

Shafer et al. (1997) determined that the characteristic partitioning behavior (between dissolved (< 0.4 Fm) and particulate (> 0.4 Fm) phases) of copper in two Wisconsin rivers exhibited very strong complexation by dissolved organic carbon (DOC) and relatively low clay partitioning. Comparing the characteristic behavior of lead (Pb), zinc (Zn), cadmium (Cd), and copper (Cu), partitioning of the metals to SPM followed the trend Pb>Zn>Cd>Cu and their association with DOC appeared to follow the trend Cu>Cd>Zn>Pb (Shafer et al., 1997).

Copper in Sediments

> ! Sediment is an important sink for copper.
> ! In aerobic sediments, the distribution of copper is dominated by its adsorption to organic matter and iron oxides in the sediment.
> ! Anoxic sediments are usually a sink for copper, but soluble Cu(I) sulfides may potentially form releasing copper into solution.

Sediment is an important sink and reservoir for copper (ATSDR, 1989). In relatively uncontaminated sediment, copper concentrations are <50 ppm, whilst contaminated sediment may contain several thousand ppm copper (ATSDR, 1989). The distribution of copper in aerobic sediments is dominated by adsorption to organic matter and iron oxides (ATSDR, 1989). In oxidized estuarine sediments, copper adsorption is dominated by amorphous iron oxides and humic material (Fuhrer, 1986, cited in ATSDR, 1989). Davies-Colley et al. (1984, cited in ATSDR, 1989) experimentally determined the adsorption of copper to hydrous iron and manganese oxides, montmorillonite, aluminosilicates, and organic matter in aerobic estuarine sediment. The binding affinity of copper varied by a factor of 10^4 in the order: hydrous manganese oxide > organic matter > hydrous iron oxide > aluminosilicates > montmorillonite. The binding affinities increased somewhat with increasing pH, but were not much affected by decreasing salinity. Given the composition of the estuarine sediment, their findings agreed with Fuhrer (1986, cited in ATSDR, 1989 and others (ATSDR, 1989 and references therein) in that copper was bound predominantly to organic matter and iron oxides (manganese oxide concentrations were low and contributed • 1% overall binding in the sediment).

In anaerobic sediments, Cu^{2+} may be reduced to Cu(I) (ATSDR, 1989). According to Davies-Colley et al. (1985 cited in ATSDR, 1989), precipitation of cuprous sulfide and the formation of copper bisulfide and/or polysulfide complexes determine the behavior of copper in anaerobic sediments. Usually, when free sulfide concentrations are low owing to the coexistence of iron oxide and sulfide, anaerobic sediments are a sink for copper. However, if free sulfide concentrations are high, soluble cuprous sulfide complexes may form giving rise to high copper concentrations in pore water (ATSDR, 1989).

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater ecosystem

Acute copper exposures to aquatic organisms have resulted in adverse effects at concentrations of 6.0 µg/L ($CuSO_4$; Cu^{2+}) for the amphipod (*Gammarus pseudolimnaeus*) and 10,200 µg/L for bluegill (*Lepomis macrochirus*). Chronic exposures to fish have resulted in adverse effects at concentrations of 3.9 µg/L to 60 µg/L for brook trout (*Salvelinus fontinalis*) and northern pike (*Esox lucius*), respectively (US EPA, 1984). Copper concentrations ranging from 1 to 8,000 µg/L (chemical form unknown) have demonstrate to cause growth inhibition in various aquatic plant species (US EPA, 1984). Data suggest that TOC has more impact in reducing the toxicity than other factors such as hardness and temperature. Effects resulting from copper exposure include growth inhibition in plants, avoidance behavior by fish, and death (US EPA, 1984). Concentrations resulting in lethality (LC_{50}s) range from 0.04 to 27 mg copper/L. Chronic toxicity tests exposing amphibian species (i.e., *Xenopus laevis*) at the tadpole stage to 0.05 mg copper/L for 4 days resulted in no effects to survival whereas no effects to metamorphosis were indicated at concentrations of 0.02 mg copper/L after 61-day exposures to other tadpole species (i.e., *Bufo boreas*) (Power et al., 1989; U.S. EPA, 1996).

Terrestrial Ecosystems

Depending on the chemical form of copper, acute LD_{50} for rats range from 140 to 960 mg/kg body weight. Copper chloride ($CuCl_2$) appears to be the more toxic form. Rat oral LD_{50} values are 140 mg/kg for copper chloride ($CuCl_2$); 470 mg/kg for copper oxide (Cu_2O); 940 mg/kg for copper nitrate ($Cu(NO_3)_2$); and 960 mg/kg for copper sulfate ($CuSO_4$) (Stokinger, 1981). Death in animals given lethal doses of copper have caused by extensive liver damage (CCME, 1997).

Aulerich et al. (1982) reported an increased mortality rate in the offspring of minks fed a diet supplemented with greater than 3 mg copper/kg-day as copper sulfate ($CuSO_4$) for 50 weeks. Although kit mortality was greater and litter mass was reduced relative to controls, reproductive performance of mink fed diets supplemented with up to 200 ppm copper for 357 days was within the normal range for the species (Aulerich et al., 1982). Lifetime exposure to 42.4 mg copper /kg-day (as copper gluconate) in drinking water caused a decrease in the maximal life span in mice (Massie and Aiello, 1984). In terrestrial plants, no effects were indicated at copper concentrations of 100 mg/kg soil, but low effects levels were indicated in the range of 100 to 200 mg/kg soil (Efroymson et al., 1997a). Soil biota appeared to be slightly more tolerant to copper exposure with no effects levels and low effects ranges of 13 to 1000 mg/kg soil and 51 to 2500 mg/kg soil, respectively, measuring toxicity endpoints of survival, growth, and reproduction (Efroymson et al., 1997b).

IV. Bioaccumulation Potential

Freshwater Ecosystems

Bioconcentration factors (BCFs) of 0 L/kg was used for copper (Cu^{2+}). This is based on the result that no bioconcentration was seen in bluegill muscle tissue. Concentration of copper in whole fish can be presumed to be close to that of whole fish (Stephan, 1993).

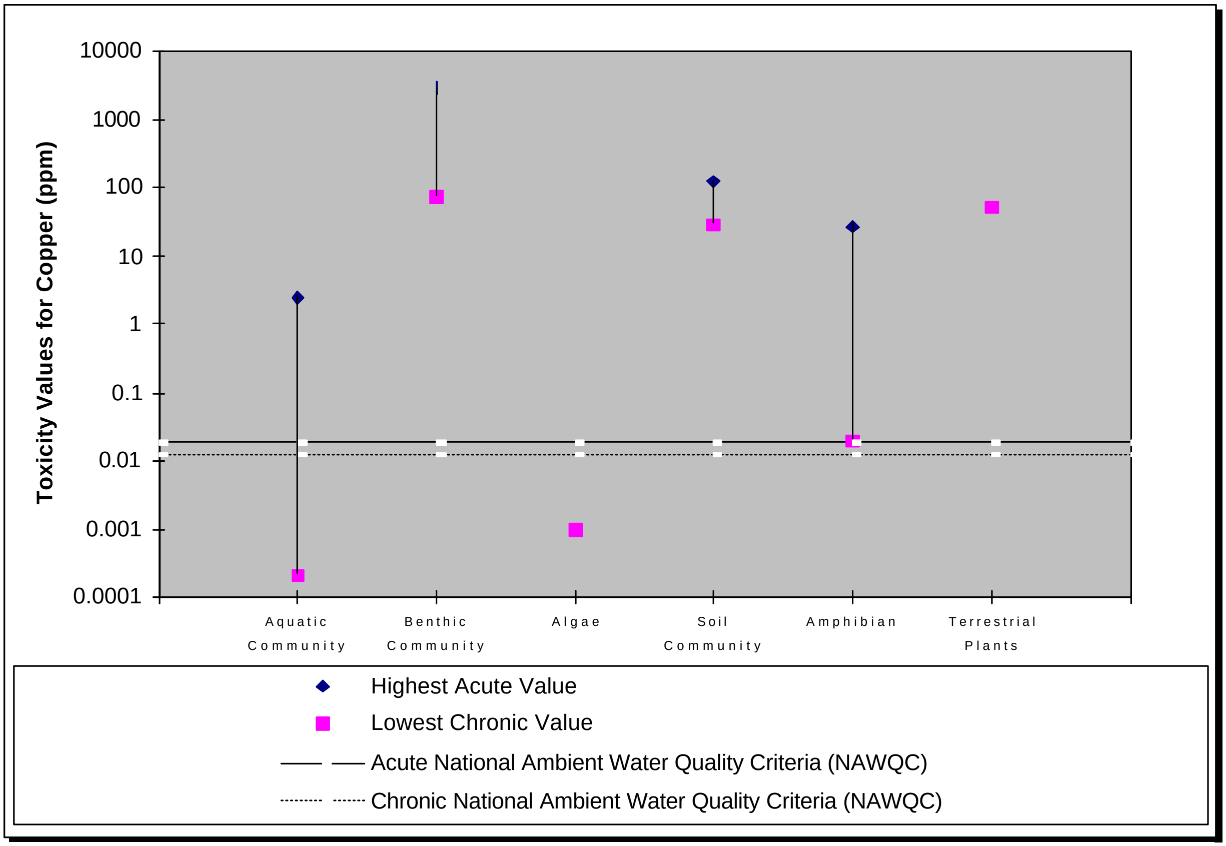

Figure 7: Copper: Effects Ranges for Ecological Receptors

Terrestrial Ecosystems

Bioaccumulation in terrestrial invertebrates, plants, and small mammals is currently being investigated at Oak Ridge National Labs. Bioaccumulation and bioconcentration factors (BAFs and BCFs) for terrestrial plants, invertebrates, and small mammals have been proposed from review of primary literature sources. The 90th percentile of the bioaccumulation data for these receptors derived from both laboratory and field studies were used to determine terrestrial food chain exposures. For earthworms, a BAF of 1.5 was proposed for copper based on 197 data points. For terrestrial plants, an BCF of 1.5 was proposed using plant uptake factors. For small mammals, based on 76 reported values assessing the transfer of copper from soil to small mammals, a BAF of 1.0 was proposed (Sample et al., 1997; Samples et al., 1998; U.S. EPA, 1992). These values were used to model food chain exposures to terrestrial species for this analysis, because currently, they stand as the most comprehensive collection of bioaccumulation data for terrestrial ecological receptors (Sample et al., 1997; 1998a; 1998b).

V. CSCL Development

The benchmark values presented in this section for mammals and birds were used to derive protective media-specific CSCLs as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor and the potential bioconcentration in prey, a protective concentration (i.e., CSCLs) in soil, plants or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. It is assumed that by protecting the more sensitive species, the other receptors are protected as well.

Mammals: Two studies were identified which investigated the effects of copper exposure in mammals. One study documented mammalian wildlife exposure to copper. Developmental endpoints were investigated in mink mating pairs fed a diet of 25, 50, 100 or 200 ppm copper for 357 days (Aulerich et al., 1982). Although no adverse effects were seen at the lowest dose, increased mortality of offspring from birth to 4 weeks occurred in the group given 50 ppm. Therefore, a NOAEL of 85.5 ppm (25 + 60.5 ppm in basal diet) and a LOAEL of 110.5 ppm (50 + 60.5 ppm in basal diet) were inferred based on these developmental effects in young mink. Conversion of these doses into daily doses in units of mg/kg-day required the use of an allometric equation for mammals (Nagy, 1987):

$$\textit{Food consumption (g/day)} = 0.235(W^{0.822})$$

where W is body weight in grams. Assuming an average body weight of 745 g (the geometric mean of the control females body weight at the start of the study (517 g) and at end of study (1,074 g)), and a calculated daily food consumption rate of 54 g/day, the NOAEL of 85.5 ppm and the LOAEL of 110.5 ppm were converted to daily doses of 6.2 mg/kg-day and 8.0 mg/kg-day, respectively. The Aulerich et al. (1982) study was considered the most suitable for the derivation of a benchmark value because (1) the mink belongs to the same taxonomic family as the representative freshwater wildlife species, and (2) doses were administered over a chronic duration and via oral ingestion, an ecologically significant exposure pathway; (3) the study focused on reproductive toxicity as a critical endpoint; and (4) it contained adequate dose-response information.

In another study, Lecyk (1980) examined copper toxicity to laboratory mice. Mating mice were fed diets containing copper doses ranging from 0.5 to 4 g/kg-diet for 1 month prior to mating until gestation day 19. No significant increases in fetal mortality or malformative effects were seen for doses of 2 g/kg-diet or less. However, higher dose levels of 3 and 4 g/kg-diet were fetotoxic and teratogenic, suggesting a NOAEL of 2 g/kg-diet and a LOAEL of 3 g/kg-diet. Since no information describing animal weights or dietary consumption was provided, the geometric mean body weight and daily food consumption from several strains of mice were used to calculate a daily dose (U.S. EPA, 1988a). Thus, assuming an average body weight of 0.035 kg and a food consumption rate of 0.014 kg/d (U.S. EPA, 1988a), the NOAEL of 2 g/kg-diet and the LOAEL of 3 g/kg-diet were converted to 800 mg/kg-day and 1200 mg/kg-day, respectively.

Because of the lack of additional mammalian toxicity studies, the same surrogate-species study (Aulerich et al, 1982) was used to derive copper toxicological benchmarks for terrestrial mammals.

Birds: No studies were identified which investigated the effects of copper toxicity in avian species.

Freshwater Community: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality

Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria (NAWQC) published by the EPA Office of Water. The FCV of 9.3E-03 mg/L for copper developed under the GLWQI was selected as the appropriate CSCL to use in this analysis. The GLWQI value was considered preferable to the NAWQC because: (1) the GLWQI value is based on the same methodology used to develop NAWQC (i.e., Stephan et al., 1985); (2) the NAWQC data set was augmented with previously unavailable acute and chronic toxicity data; and (3) species taxa used to generate the GLWQI value is suitable for national application since they include species and taxa found throughout the United States. The toxicity of copper is hardness dependent; therefore, the FCV (in µg/L) was calculated using the following equation (U.S. EPA, 1995a), assuming a water hardness of 100 mg/L as calcium carbonate ($CaCO_3$):

$$e^{0.8545(\ln \text{hardness}) - 1.702}$$

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metals concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). Consequently, the FCV for copper was adjusted to provide dissolved concentrations as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). The copper FCV was adjusted using a conversion factor (CF) of 0.960 for chronic effects to give a dissolved surface water CSCL of 8.9E-03 mg/L. This adjustment reflects the current Agency position on criteria development and regulatory application of metals; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). For example, the relationship between water characteristics (e.g., dissolved organic matter), copper bioavailability, and toxicity has been investigated in some detail (e.g., Allen and Hansen, 1996). For completeness, the total and dissolved surface water CSCLs are presented in Table 1.

Amphibians: No suitable subchronic or chronic studies were identified which studied the effects of copper toxicity on reproductive or developmental endpoints in amphibian species; however, several acute studies were identified characterizing copper toxicity. Review of data collected from 14 experiments indicate that the acute toxicity of copper ranges from 0.04 to 27 mg/L, with a geometric mean of 1.1 mg/L. Acute studies were conducted on various amphibian species (i.e., twelve amphibian species represented) during embryo, tadpole, and adult lifestages. Chemical exposures were conducted with copper chloride and copper sulfate. The observation that the lowest acute amphibian value is still higher than the FAV, of 0.018 mg copper/L determined for the freshwater community indicates that many amphibian species may be protected from acute exposures by the aquatic community FAV. Subchronic ecotoxicity data identified indicated a NOEC and LOEC of 0.05 and 0.10, respectively for the species *Xenopus laevis*; however, this data was generated using 96-hour exposures which may not indicate the extent of chronic effects that may be observed during longer exposures (e.g., greater than 15 days). One study indicated after exposure to 0.02 mg copper/L for 61 days no effect to metamorphosis was observed. Given the lack of chronic amphibian data, a CSCL of 1.1 mg copper/L was proposed based on acute toxicity. Since the CSCL is based on acute data (i.e., lethality), the severity of the potential adverse effects that this CSCL indicates should be noted. Especially since LOEC and NOEC data fall below the acute CSCL. Investigations are ongoing to review the possibility of incorporating amphibian data into the NAWQC. Since amphibian species are more likely to breed in standing waters such as wetlands or ponds, the appropriateness of combining protective levels of amphibian receptors and the freshwater community is unclear at this time (Power et al., 1989; U.S. EPA, 1996).

<u>Algae and Aquatic Plants</u>: The benchmarks for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or (2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). The aquatic plant CSCL for copper is 1E-03 mg/L based on a lag in growth of alga (Suter and Tsao, 1996). Low confidence is placed in this CSCL since it is only based on one study.

<u>Benthic Community</u>- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, criteria are developed estimating the 10th percentile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). These values are not NOAA standards; rather, they are used to rank sites based on the potential for adverse ecological effects. A second criteria document evaluated for sediment criteria development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the criteria was changed. FDEP calculated the criteria (i.e., threshold effects level, TEL) from the geometric mean of the 50^{th} percentile of no effects data and the 15^{th} percentile of the low effects data. The NOAA data, used in both documents, is based on total metal concentrations in sediments, and the toxicity endpoints were measured on species of amphipods, arthropods, and bivalves in addition to a variety of community-based endpoints (e.g., abundance, mortality, species composition, species richness). The FDEP criterion was chosen above the NOAA criterion for the following reasons; (1) the same database was used for both the NOAA criteria and the FDEP criteria development only different derivation methods were used; (2) in most cases, the FDEP criterion was more conservative than the NOAA criteria because a larger portion of the low effects data was used in criteria development; (3) the marine TEL developed by the FDEP were found to be analogous to TELs observed in freshwater organisms (Smith et al., 1995).

The CSCL for copper was derived from 440 toxicity data points for low and no effects levels. For the screening level analysis of copper, the TEL of 1.9E+01 mg copper/kg sediment was selected as an appropriate sediment CSCL. Based on the quality and quantity of copper sediment data, the degree of confidence in the TEL value for copper was considered high (MacDonald, 1994).

<u>Terrestrial Plants</u>: As presented in Efroymson et al. (1997a), phytotoxicity CSCLs were selected by rank ordering the lowest observable effects concentration (LOEC) values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the CSCL. Such LOECs applied to reductions in plant growth, yield, or seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. The selected CSCL for phytotoxic effects of copper in soils is 100 mg copper/kg soil (Efroymson et al., 1997a) based on reduced root and shoot weights in little bluestem. The derivation of the CSCL is based on comparison of three phytotoxicity data points on agricultural (e.g., barley, beanbush) species measuring growth endpoints such shoot and root weight. Considering this CSCL was based on limited phytotoxicity data on only a few species (e.g., choosing the lowest values of the three data points), confidence in this CSCL is low.

<u>Soil Community</u>: CSCLs for soil from community-based effects presented in Hazardous Waste

Identification Rule (RTI, 1995b) of 21 mg/kg was proposed for copper. This value developed from various different soil-based organisms may be more appropriate than CSCLs which are based on single soil species such as earthworms. Calculation of the CSCLs involves incorporating the no observed effects concentration (NOEC) and lowest observed effects concentration (LOEC) data set for soil biota and to a statistically derived formulation designed to protect 95% of the species potentially present in soil. The CSCLs proposed herein will provide long-term sustainability of a functioning soil community for multiple uses of the affected area, such as agriculture and residential use (RTI, 1995b). Because 10 studies were used to derive this value, confidence in this CSCL is moderate.

Table 1. Copper CSCLs in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Mammals	4.0E+01	mg/L water	Food web	River Otter	Aulerich et al., 1982
Birds	5.9E+02	mg/L water	Food web	Kingfisher	Sample et al., 1996
Algae and Aquatic Plants	1.0E-03	mg/L water	Direct contact	Algae species	Suter and Tsao, 1996
Freshwater Community					
Total	9.3E-03	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1995b
Dissolved	8.9E-03	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1995b; 60FR22229
Benthic Community	1.9E+01	mg/kg sediment	Direct contact	Benthos	MacDonald, 1994
Amphibian (acute effects)	1.1E+00	mg/L water	Direct contact	Various amphibian species	Power et al., 1989; U.S. EPA, 1996
Terrestrial					
Mammals	8.0E+02	mg/kg soil	Food web	Raccoon	Aulerich et al., 1982
Birds	9.1E+02	mg/kg soil	Food web	American woodcock	Sample et al., 1996
Mammals	4.1E+01	mg/kg plant tissue	Food web	Meadow vole	Aulerich et al., 1982
Birds	9.0E+02	mg/kg plant tissue	Food web	Northern bobwhite	Sample et al., 1996
Plant Community	1.0E+02	mg/kg soil	Direct contact	Bluestem	Efroymson et al., 1997a
Soil Community	2.1E+01	mg/kg soil	Direct contact	Soil invertebrates	RTI, 1995b

Ecotoxicological Profile for Ecological Receptors
Lead

This ecotoxicological profile on lead contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (5) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of lead so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

Lead is a non-essential, highly toxic heavy metal for which all known effects on biological systems are deleterious. Lead is present in low concentrations throughout the environment as a result of geologic weathering, with an average abundance in the earth's crust of 16 ppm. Human activities, have resulted in a widespread increase in lead residues in the environment. In soils, natural background concentrations are generally on the order of 10 to 30 ppm, but near lead emissions sources such as roadways, concentrations of up to 2000 ppm have been found.

Naturally-occurring lead has three oxidation states: elemental (0), divalent (+2), and tetravalent (+4). In its inorganic forms, lead is found primarily in the divalent state. Organolead compounds, the most important of which are tetramethyl and tetraethyl lead, are formed predominantly by lead in the tetravalent state, and are considered to be the more toxic forms. In most of its forms, except for some lead salts, lead is relatively insoluble in water and tends to accumulate in sediments. The majority of lead ingested by biota is rapidly egested (Eisler, 1988b). Inhaled lead, though, is absorbed quickly by blood (ATSDR, 1993e). Lead does bioconcentrate, and older organisms tend to have the highest body burdens. Biomagnification of lead in the food chain, though, has been found to be negligible (Eisler, 1988b).

II. Geochemistry of Lead in Various Ecological Media

Lead in Soils

- Lead speciation in soils is dependent on physico-chemical processes including adsorption, precipitation, and complexation.
- Most lead in soils is strongly sorbed to organic matter and very little is transported to surface or ground water.

The speciation of lead in soils is dependent on physico-chemical processes including adsorption, precipitation, and complexation with solid and aqueous inorganic and organic phases within the soil. These processes are themselves determined by such factors as soil pH, organic matter concentrations, lead concentrations, and the presence of other inorganic components (NSF, 1977, cited in ATSDR, 1993). The atmospheric deposition rate for lead is the primary factor defining its accumulation in most soils (ATSDR, 1993).

Most of the lead in soils is strongly sorbed to organic matter and very little is transported to surface water or ground water (ATSDR, 1993). Ion exchange processes with hydrous oxides or clays, or chelation with humic or fulvic acids can remove lead from solution in soil (Olson and Skogerboe, 1975, cited in ATSDR, 1993). In soils with pH $\geq$ 5 and $\geq$ 5% organic matter content, atmospheric lead is retained within the uppermost 2-5 cm of undisturbed soil (ATSDR, 1993). In soils with pH 6-8 and a high organic matter content, lead can form insoluble organo-complexes. Within the same pH range but with a lower organic matter content, hydrous lead oxide complexes may form or lead may precipitate out with carbonate or phosphate ions (ATSDR, 1993). At lower pHs of 4-6 organo-lead complexes may be soluble (EPA, 1986a, cited in ATSDR, 1993).

<u>Lead in Surface Waters</u>

A review of trace elements in rivers by Hart and Hines (1995) tabulated typical dissolved (i.e. <0.4 μm) lead concentrations ranging from 87 - 1,800 ng/l. The behavior of lead in rivers is primarily controlled by the balance between complexation with dissolved organic matter, and association with suspended particulate matter (SPM) and colloidal matter (Hart and Hines, 1995). Particles settling through surface waters can control the behavior of elements like lead which are removed from the dissolved phase (usually < 0.4 μm) by forming nuclide/particle surface site complexes (Santschi, 1988 and references therein). Reactions with dissolved and particulate organic carbon can also regulate the concentration of organically complexed elements like lead. These reactions can be particularly important in coastal waters which have high organic loadings and in estuarine environments which have large ionic strength gradients (Santschi, 1988).

- The behavior of lead is primarily controlled by the balance between complexation with dissolved organic matter, and association with SPM and colloids.
- In a study of three U.S. rivers, lead was found to be partitioned between particulate, colloidal, and "truly" dissolved phases. Partitioning between filter-retained and filtrate lead showed a dependence on the concentration of total SPM.

Benoit (1995) determined lead concentrations in fresh water from three rivers in the northeast United States and investigated the relationship between lead in particulate, colloidal, and "truly" dissolved (i.e., occurring as individual solvated ions) phases. Partitioning between (0.45 μm) filter-retained and filtrate (< 0.45 μm) fractions exhibited a dependence on the concentration of total suspended solids (Benoit, 1995). This phenomenon, called the particle concentration effect, can be explained by the contribution of lead bound to colloids which are included in the filter-passing fraction of conventionally "dissolved" trace elements (Benoit, 1995 and references therein). Benoit (1995) calculated the "true" partition coefficient for lead to be greater than $10^{7.4}$ (compared to partition coefficients of ~10^5 to 10^8 for filter retained/filtrate lead), indicating that truly dissolved lead concentrations were extremely low.

<u>Lead in Sediments</u>

In anaerobic lake sediments, relatively volatile organo- (tetramethyl) lead may form through biological alkylation of organic and inorganic lead compounds (EPA, 1979d, cited in ATSDR, 1993).

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystem

Lead is toxic to aquatic biota, though effects are significantly modified by various factors. Waterfowl suffering from lead intoxication exhibit symptoms such as lethargy and emaciation (chemical form unknown). In birds, death usually is indirectly caused by starvation and vulnerability to predation (Eisler, 1988b). Acute exposures of lead to aquatic invertebrates and fish of 1 to 500 mg Pb/L have lethal effects; chronic exposures over extended durations to concentrations ranging from 0.007 to 0.020 mg/L can also have lethal effects (chemical form unknown). Aquatic invertebrate species in general show a wide range of sensitivity to lead exposures. Chronic exposures of 0.019 mg/L have been found to increase mortality in marsh snails *(Lymnaea palustris)* (Demayo et al., 1982). Adverse effects on daphnid reproduction have been observed at 0.001 mg Pb^{2+}/L (Eisler, 1988b). In fish, lethal solutions of lead promote the formation of increased mucus, which coagulates over the entire body and gills, resulting in suffocation (Eisler, 1988b). Developmental defects are reported in rainbow trout exposed to 7.6 µg/L over 19 months (Davies et al., 1976). Effects of lead poisoning in amphibians include the alteration of blood chemistry, sluggishness, vision impairment, and sloughing of skin (Eisler, 1988b; Hoffman et al., 1995). Exposure of embryonic toads, *Xenopus laevis*, to static concentrations of 0.001 mg/L resulted in deformation of 82% of the population and 18% mortality, whereas 10 mg/L resulted in 100% mortality (Power et al., 1989).

Terrestrial Ecosystem

Lead acts at the molecular level to inhibit enzymes necessary for normal biological function in a variety of biota. In mammals, lead toxicity may affect the hematological system, the brain and nervous system, learning and behavior, and reproduction (Hoffman et al., 1995). In cattle, studies suggest that acute sublethal or lethal poisoning generally occurs at doses of 5 to 7 mg/kg-day (Hoffman et al., 1995). Decreases in survival rates in mice have been reported at drinking water exposures of 5 mg/L (Demayo et al., 1982). In rats, oral doses of 0.01 to 0.02 mg/kg-day have been associated with reproductive impairment and neurological problems (Hilderbrand et al., 1973 ; Krasovskii et al., 1979). Lead may also weaken an organism's immune system, even when no other signs of lead toxicity are observed (Hoffman et al., 1995). In birds, reproductive and developmental effects include decreases in egg production at 1.53 mg/kg-day oral exposures

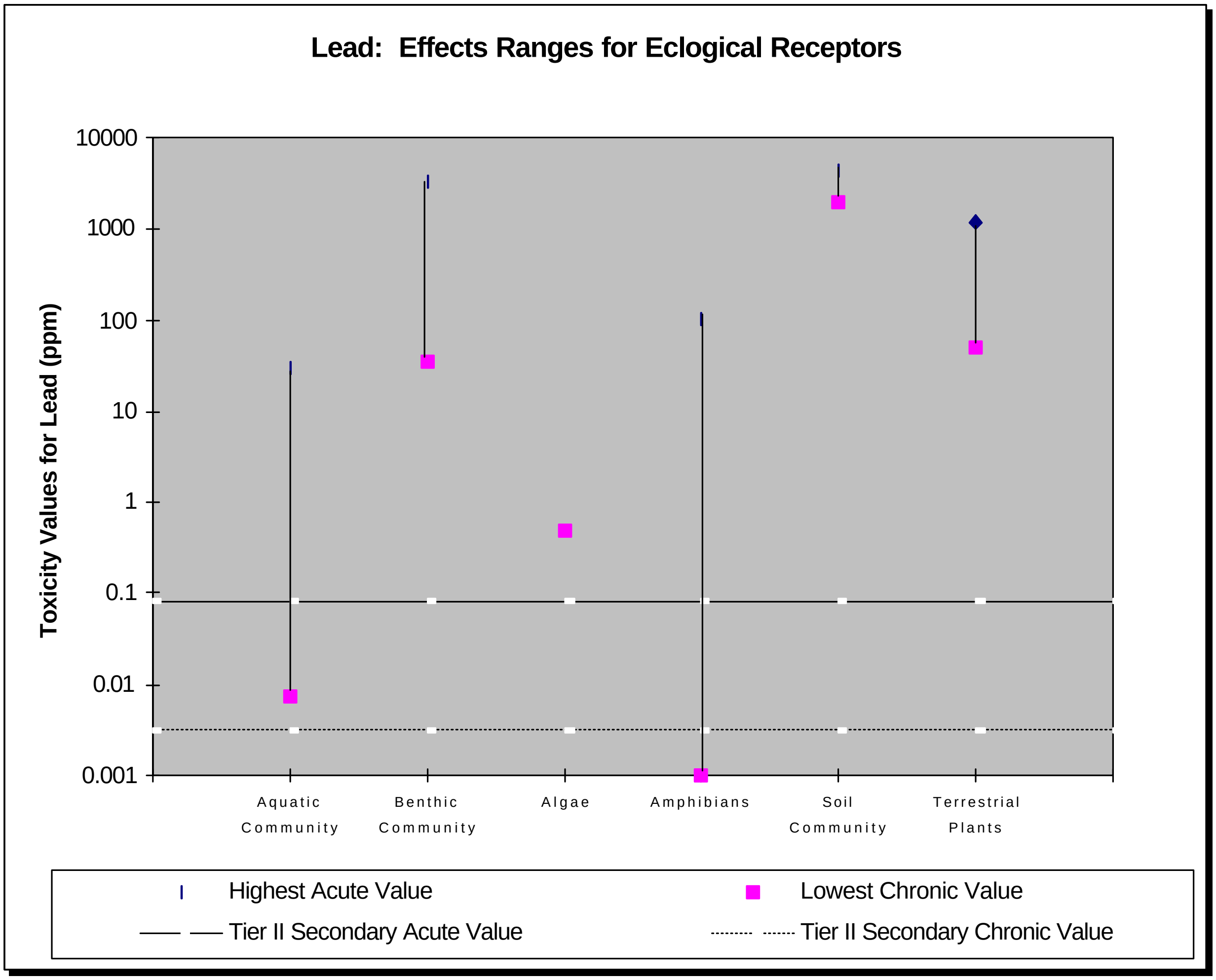

Figure 8: Lead: Effects Range for Selected Ecological Receptors

in Japanese quail and inhibited growth rates at 125 mg/kg-day in the American kestrel (Edens and Garlich, 1983; Hoffman et al., 1985).

Damage to plants with elevated lead contents is often negligible, but does vary among species. Lead can have deleterious effects on plants at current lead levels in urban areas (Eisler, 1988b). The decline of some European spruce forests has been attributed to excessive concentrations of atmospheric lead. Reported effects include inhibition of plant growth, and reductions in pollen germination, seed viability, and rates of photosynthesis and transpiration (Hoffman et al, 1995). Terrestrial plants indicate low level effects at concentrations ranging from 50 to 500 mg/kg soil (Efroymson et al., 1997a).

IV. Bioaccumulation Potential

Freshwater Ecosystems
Lead inhibits photosynthesis and algal growth by 64% at concentrations of 0.1 mg Pb/L (Demayo et al., 1982); however, water quality parameters (e.g., pH) will influence the observed toxicity and may affect an aquatic plants' sensitivity to lead (Demayo et al., 1982). Lead is

bioconcentrated by aquatic organisms, but there is little evidence of biomagnification through the food chain (ATSDR, 1993e). Lead tissue concentrations tend to decrease with increasing aquatic trophic level, with the highest levels found in benthic organisms and algae and the lowest in upper trophic level predators (Eisler, 1988b). Bioaccumulation factor (BAF) if 45.7 L/kg for fish was used to predict food chain exposures for piscivorous mammals and birds (unspecified chemical form) (Stephan, 1993). The value is based on a whole-body measured BAF of bluegill sunfish (*Lepomis macrochirus*).

Terrestrial Ecosystems
Bioaccumulation in terrestrial invertebrates, plants, and small mammals is currently being investigated at Oak Ridge National Labs. Bioaccumulation and bioconcentration factors (BAFs and BCFs) for terrestrial plants, invertebrates, and small mammals have been proposed from review of primary literature sources. The 90^{th} percentile of the bioaccumulation data for these receptors derived from both laboratory and field studies were used to determine terrestrial food chain exposures. For earthworms, a BAF of 1.5 was proposed for lead based on 245 data points. For terrestrial plants, an BCF of 0.62 was proposed based on 204 data points. For small mammals, based on 138 reported values assessing the transfer of lead from soil to small mammals, a BAF of 0.29 was proposed (Sample et al., 1997; Samples et al., 1998). These values were used to model food chain exposures to terrestrial species for this analysis, because currently, they stand as the most comprehensive collection of bioaccumulation data for terrestrial ecological receptors (Sample et al., 1997; 1998a; 1998b).

V. CSCL Development

The benchmark values presented in this section for mammals and birds were used to derive protective media-specific CSCLs as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor and the potential bioconcentration in prey, a protective concentration (i.e., CSCLs) in soil, plants or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. It is assumed that by protecting the more sensitive species, the other receptors are protected as well.

Mammals: Numerous studies were identified that addressed the effects of lead in mammals. In an experiment lasting 20-30 days, rats were administered lead in oral doses of 0.05, 0.005 and 0.0015 mg/kg-day (Krasovskii et al., 1979). Impairment of the functional capacity of the male rat's spermatozoa was observed in rats receiving the maximum dose of 0.05 mg/kg-day. The gonadotoxic effects at 0.05 mg/kg-day resulted in an inferred NOAEL of 0.005 mg/kg-day. In another experiment in the same study, male and female rats were given the same doses of lead as above for 6-12 months. Neurological deficits, including disruption of conditional responses and motor activity, were observed at 0.05 and 0.005 mg/kg-day.

The NOAEL for gonadotoxic effects from the Krasovskii et al. (1979) study was chosen to derive the toxicological benchmark for the following reasons: (1) doses were administered over a chronic duration and via oral ingestion, an ecologically significant exposure pathway; (2) it focused on irregularities in the male rat's reproductive system as a critical endpoint; (3) it contained dose response information; and (4) it resulted in the lowest toxicity value for a critical endpoint.

In another investigation, dogs that were given a single dietary dose of 0.32 mg/kg-day for an unspecified period of time exhibited clinical signs of chronic lead toxicity (Demayo et al., 1982). Also, Hilderbrand et al. (1973) treated male and female rats with oral doses of lead of 5 and 100 µg/day for 30 days. Gonadotoxic effects in both the male and female rats were observed at the 100 µg/day dose resulting in an inferred NOAEL of 5 µg/day. To obtain the NOAEL as a daily dose, the reported dose was divided by the geometric mean (0.235 kg) of the male and female rats' reported body weights, resulting in a daily dose of 0.02 mg/kg-day.

The study by Hilderbrand et al., (1973) was not selected for the derivation of a benchmark because it did not report the lowest toxicity value for a critical endpoint. The Demayo et al. (1982) study was not chosen because of the absence of sufficient dose-response information and lack of critical endpoints.

The same surrogate-species study (Krasovskii et al., 1979) was used to derive the lead benchmark for mammalian species representing the terrestrial ecosystem.

<u>*Birds*</u>: There were several studies that investigated the effects of lead toxicity on birds. In a series of experiments, Edens and Garlich (1983) monitored the egg production of chickens and Japanese quail. Results showed that Japanese quail are more sensitive than chicken hens. When the lowest dose of 1 mg Pb/kg feed was administered for five weeks from day of hatch, egg production in Japanese quail was significantly reduced. This resulted in a reported LOAEL of 1 mg/kg-feed. This corresponds to a daily dose of 0.21 mg/kg-day based on a body weight value of 0.150 kg and a food intake value of 0.031 kg/day, both obtained from the study. In the absence of an experimental NOAEL, the NOAEL used is extrapolated from LOAEL of 0.21 mg/kg-day by a factor of 10 to arrive at an estimated NOAEL of 0.021 mg/kg-day.

The LOAEL reported by Edens and Garlich (1983) for Japanese quail was selected to derive the avian benchmark value for the freshwater ecosystem. This study was chosen for the following reasons: (1) doses were administered via oral ingestion, an ecologically significant exposure pathway; (2) it focused on reproductive toxicity as a critical endpoint; (3) it contained dose response information; and (4) it resulted in the lowest toxicity value for a critical endpoint.

Growth rate suppression occurred in chickens exposed to 1850 ppm of dietary lead for 4 weeks (Franson and Custer, 1982). Conversion of this dose into units of mg/kg-day required the use of an allometric equation for chickens (U.S. EPA, 1988a):

$$\textit{Food consumption (kg/day)} = 0.075(W^{0.8449})$$

where W is body weight in kilograms. Based on the geometric mean of reported body weights of 0.110 kg for the control birds and the derived food consumption rate of 0.012 kg/day, the 1850 ppm dose corresponds to a daily dose of 202 mg/kg-day. In another study, American kestrels exposed to doses of 10 and 50 ppm for 6 months exhibited no impairment of survival, egg laying, fertility, or eggshell thickness, suggesting a NOAEL of 50 ppm (Pattee, 1984). Conversion of this dose into units of mg/kg-day required the use of an allometric equation for birds (Nagy, 1987):

$$\textit{Food consumption (g/day)} = 0.648(W^{0.651})$$

where W is body weight in grams. Using a reference kestrel body weight of 120 g (U.S. EPA, 1993h) and a calculated food consumption rate of 15 g/day, the 50 ppm dose was converted to a daily dose of 6.3 mg/kg-day. In another study, Hoffman et al., (1985) examined the growth of one-day old American kestrel nestlings exposed orally to 25, 125 and 625 mg/kg-day of dietary lead. The authors reported a NOAEL of 25 mg/kg-day and a LOAEL of 125 mg/kg-day.
The other studies mentioned above were not selected, either because they did not focus on a reproductive endpoint or because they lacked sufficient dose-response information.

Freshwater Community: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria (NAWQC) published by the EPA Office of Water. The FCV of 3.2E-03 mg/L for lead and developed under the NAWQC was selected as the appropriate criteria to use in this analysis because no criteria were available for lead under GLWQI work (U.S. EPA, 1986c). The GLWQI value was considered preferable to the NAWQC because: (1) the GLWQI value is based on the same methodology used to develop NAWQC (i.e., Stephan et al., 1985); (2) the NAWQC data set was augmented with previously unavailable acute and chronic toxicity data; and (3) species taxa used to generate the GLWQI values are suitable for national application since they include species and taxa found throughout the United States. But lacking the GLWQI value for lead, the NAWQC was used. It should be noted that the toxicity of lead is hardness dependent; therefore, the FCV (in µg/L) was calculated using the following equation (U.S. EPA, 1995a), assuming a water hardness of 100 mg/L as calcium carbonate ($CaCO_3$):

$$e^{(1.273(\ln \text{hardness})-4.705)}$$

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metal concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). Consequently, the FCV for lead was adjusted to provide dissolved concentrations as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). The lead FCV was adjusted using a conversion factor (CF) of 0.791 for chronic effects to give a dissolved surface water CSCL of 2.5E-03 mg/L. This adjustment reflects the current Agency position on criteria development and regulatory application of metals; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). For example, the relationship between water characteristics (e.g., dissolved organic matter), copper bioavailability, and toxicity has been investigated in some detail (e.g., Allen and Hansen, 1996). For completeness, the total and dissolved surface water criteria are presented in Table 1 even though the values are identical.

Amphibians: No suitable subchronic or chronic studies were identified for CSCL development which studied the effects of lead toxicity on reproductive or developmental endpoints in amphibian species. The variability between experimental designs and test endpoints made consistent comparisons between chronic data prohibitive; however, both acute and chronic data were identified to characterize the toxicity of lead to amphibian species. Review of data collected from six experiments indicate that the acute toxicity of lead ranges from 0.04 to 105 mg/L, with a geometric mean of 2.1 mg/L. Acute and chronic studies were conducted on various amphibian species (i.e., eleven amphibian species represented) during embryo, tadpole and adult lifestages. Developmental deformities were noted in embryos of *Xenopus laevis* exposed to lead concentrations of 1 to 3 mg lead/L. Other behavioral responses to lead exposure are indicated at concentrations ranging from 0.5 to 1 mg lead/L The observation that the lowest acute amphibian value approximates (i.e., within a factor of two) the FAV, of 0.082 mg lead/L determined for the freshwater community indicates that a large percentage of amphibian species may be protected at concentrations protective of the aquatic community. Given the inconsistency in reported chronic data, a CSCL of 2.1 mg lead/L was derived based on acute toxicity. Since the CSCL is based on acute data (i.e., lethality), the severity of the potential adverse effects that this CSCL indicates should be noted. Investigations are ongoing to review the possibility of incorporating amphibian data into the NAWQC. Since amphibian species are more likely to breed in standing waters such as wetlands or ponds, the appropriateness of combining protective levels of amphibian receptors and the freshwater community is unclear at this time (Power et al., 1989; U.S. EPA, 1996).

Algae and Aquatic plants: Relevant endpoints for aquatic plants focused on the ability of plants to support higher trophic levels as well as the ability to provide habitat for other species in the freshwater ecosystem. The CSCLs for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or (2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). For lead the CSCL value was determined to be 5.0E-01 mg/L based on the growth inhibition of *Chlorella vulgaris, Scenedesmus quadricauda*, and *Selenastrum capricornutum* (Suter and Tsao, 1996). Moderate confidence is placed in this CSCL since it is only based on several studies.

Benthic Community- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, CSCLs are developed estimating the 10th percentile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). These values are not NOAA standards; rather, they are used to rank sites based on the potential for adverse ecological effects. A second criteria document evaluated for sediment criteria development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the criteria was changed. FDEP calculated the criteria (i.e., threshold effects level, TEL) from the geometric mean of the 50^{th} percentile of no effects data and the 15^{th} percentile of the low effects data. The NOAA data, used in both documents, is based on total metal concentrations in sediments, and the toxicity endpoints were measured on species of amphipods, arthropods, and bivalves in addition to a variety of community-based endpoints (e.g., abundance, mortality, species composition, species richness). The FDEP criterion was chosen above the NOAA criterion for the following reasons; (1) the same database was used for both the NOAA criteria and the FDEP criteria development only different derivation methods were used; (2) in most cases, the FDEP criterion was more conservative than the NOAA criteria because a larger portion of the low effects data was used in CSCL development; (3) the marine TEL developed by the FDEP were found to be analogous to

TELs observed in freshwater organisms (Smith et al., 1995).

The CSCL for lead was derived from 402 toxicity data points for low and no effects levels. For the screening level analysis of lead, the TEL of 3.0E+01 mg lead/kg sediment was selected as an appropriate sediment CSCL. Based on the quality and quantity of lead sediment data, the degree of confidence in the TEL value for lead was considered high (MacDonald, 1994).

Terrestrial Plants: As presented in Efroymson et al. (1997a), phytotoxicity CSCLs were selected by rank ordering the lowest observable effects concentration (LOEC) values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the CSCL. Such LOECs applied to reductions in plant growth, yield, or seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. The selected CSCL for phytotoxic effects of lead in soils is 50 mg lead/kg soil (Efroymson et al., 1997a). The derivation of the CSCL is based on 17 phytotoxicity data points on various agricultural (e.g., barley, ryegrass) and silverculture (e.g., spruce) species measuring growth endpoints such as height and weight of shoots and roots, yield, and germination success. Considering this CSCL was based on multiple studies over a range of species, confidence in this CSCL is high.

Soil Community: CSCLs for soil from community-based effects presented in Hazardous Waste Identification Rule (RTI, 1995b) of 28 mg/kg was proposed for lead. This value developed from various different soil-based organisms may be more appropriate than CSCLs which are based on single soil species such as earthworms. Calculation of the CSCLs involves incorporating the no observed effects concentration (NOEC) and lowest observed effects concentration (LOEC) data set for soil biota and to a statistically derived formulation designed to protect 95% of the species potentially present in soil. The CSCLs proposed herein will provide long-term sustainability of a functioning soil community for multiple uses of the affected area, such as agriculture and residential use (RTI, 1995b). Because 8 studies were used to derive this value, confidence in this CSCL is moderate.

Table 1. Lead CSCLs in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Mammals	3.0E-04	mg/L water	Food web	River Otter	Krasovskii et al., 1979
Birds	9.0E-04	mg/L water	Food web	Kingfisher	Eden and Garlich, 1983
Algae and Aquatic Plants	5.0E-01	mg/L water	Direct contact	*Chlorella vulgaris* and others	Suter and Tsao, 1996
Freshwater Community					
Total	3.2E-03	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1986c
Dissolved	2.5E-03	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1986c; 60FR22229
Benthic Community	3.0E+01	mg/kg sediment	Direct contact	Benthos	MacDonald, 1994
Amphibians (acute effects)	2.1E+00	mg/L water	Direct contact	Various amphibian species	Power et al., 1989; U.S. EPA, 1996
Terrestrial					
Mammals	4.7E-01*	mg/kg soil	Food web	Raccoon	Krasovskii et al., 1979
Birds	1.6E-01*	mg/kg soil	Food web	American woodcock	Eden and Garlich, 1983
Mammals	2.4E-02	mg/kg plant tissue	Food web	Meadow vole	Krasovskii et al., 1979
Birds	2.9E-01	mg/kg plant tissue	Food web	Northern bobwhite	Eden and Garlich, 1983
Plant Community	5.0E+01	mg/kg soil	Direct contact	Sycamore, red oak	Efroymson et al., 1997a
Soil Community	2.8E+01	mg/kg soil	Direct contact	Soil invertebrates	RTI, 1995b

* This CSCL should not be used because it is below soil background concentrations (lowest mean background concentration 16 mg lead/kg soil) . This may be an artifact of our back-calculation method (i.e., calculating media-specific criteria from the benchmark study).

Ecotoxicological Profile for Ecological Receptors
Mercury

This ecotoxicological profile on mercury contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (5) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of mercury so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

Mercury occurs naturally as a mineral and is distributed throughout the environment by natural and anthropogenic processes. Natural processes include weathering of mercury-containing rocks and volcanic eruptions. Anthropogenic releases are primarily to the atmosphere. Major anthropogenic sources of mercury include mining; industrial processes involving the use of mercury, including chloralkai manufacturing facilities; combustion of fossil fuels, primarily coal; production of cement; and medical and municipal waste incineration. Background concentrations in soils range from less than 0.01 to 4.6 mg Hg/kg soil (Dragun and Chiasson. 1991). Typical concentrations in uncontaminated river waters range from 0.1 to 0.5 µg Hg/L with ground water sources demonstrating the high end of this range. Sediments which can act as a sink for mercury contain background concentrations of 0.02 to 0.06 mg Hg/kg, although polluted sediments may have 0.1 to 746 mg Hg/kg (Eisler, 1987).

Mercury exposure has been linked to adverse effects to a multitude of species including plants, fish, aquatic invertebrates, birds, and mammals. In both aquatic and terrestrial plants, decreased growth, reduced photosynthesis, inhibition of metabolic enzymes, leaf injury (e.g., necrosis), and lethality have been reported. Aquatic receptors, such as fish and invertebrates, have demonstrated death, reduced reproduction, impaired growth and development, altered behavior and metabolic function. Avian and mammalian species demonstrate sublethal effects such as organ damage, decreased growth and reproduction, and behavioral modifications.

Mercury in the aquatic system is known to undergo microbially-mediated biotransformation to form methylmercury which is a more bioavailable and toxic compound than inorganic mercury in aquatic systems. Mercury, unlike other metals, bioaccumulates and biomagnifies up the food chain creating potentially high exposures to piscivorus mammals and birds. Methylation of mercury results in significant exposure for receptors of the aquatic community, including those avian species who consume large quantities of fish in their diet (U.S. EPA, 1996).

II. Geochemistry of Mercury in Various Ecological Media

General

Mercury occurs naturally as a mineral and is distributed throughout the environment by natural and anthropogenic processes. Mercury can exist in three oxidation states, Hg^0 (elemental), Hg^+ (mercurous), and Hg^{2+} (mercuric). The most reduced form is elemental mercury (Hg^0), which is a liquid at ambient temperatures but readily vaporizes. Mercurous and mercuric mercury can form numerous inorganic and organic chemical compounds; however, mercurous mercury is rarely stable under ordinary environmental conditions.

- Mercury can exist in the environment in three oxidation states, including Hg^0, Hg^+, and Hg^{2+}.
- Elemental mercury (Hg^0) readily vaporizes.
- Mercurous mercury (Hg^+) is rarely stable under ordinary environmental conditions.
- The compounds most likely to be found under environmental conditions are: the mercuric salts [$HgCl_2$, $Hg(OH)_2$, and HgS] and the methylmercury compounds [CH_3HgCl and CH_3HgOH].
- Methylmercury is the most common organic form of mercury. It is soluble, mobile, and quickly enters the food chain.

Mercury is unusual among metals in that it tends to form covalent rather than ionic bonds. Most of the mercury encountered in the water/soil/sediments/biota (all environmental media except the atmosphere) is in the form of inorganic mercuric salts and organomercuries. Organomercuries are defined by the presence of a covalent C-Hg bond. This is thought to differ from the common behavior of inorganic mercury compounds associating with organic material in the environment. The compounds most likely to be found under environmental conditions are: the mercuric salts $HgCl_2$, $Hg(OH)_2$, and HgS; the methylmercury compounds CH_3HgCl and CH_3HgOH; and in small fractions, other organomercuries (i.e., dimethylmercury and phenylmercury).

Mercury in Soils

Average mercury concentrations in virgin and cultivated surface soils range from 20 to 625 ng/g. The highest concentrations are generally found in soils from urban locations and in organic versus mineral soils. The mercury content of most soils varies as a function of depth, with the highest mercury concentrations generally found in the surface layers.

- Mercury is strongly sorbed to soil substrates at pH values equal to or greater than 4.
- Adsorption-desorption reactions with organic matter and soil minerals control soil pore water concentrations to very low levels.
- Chloride concentration may be as important as pH in determining mercury mobility.
- Mercury may also be mobilized through the reduction of ionic mercury to the more volatile elemental mercury and through methylation to form volatile organic compounds such as dimethylmercury.

Mercury is readily sorbed to soil substrates. It is strongly sorbed to humic materials in soils characterized by pH values equal to or greater than 4. It is also sorbed to iron oxides and clay minerals. Inorganic mercury sorbed to particulate material is not readily desorbed, and as a consequence, leaching is relatively insignificant. Adsorption-desorption reactions with organic matter and soil minerals control soil pore water concentrations to very low levels.

Although mercury is thought to be strongly sorbed to the soil substrate, adsorption may be decreased, and mercury re-mobilized, as a function of increasing pH and/or chloride ion content. Mercuric mercury (Hg^{2+}) may form various complexes with chloride and hydroxide ions in soils. It is generally accepted that chloride is the most significant inorganic ligand responsible for increasing the mobility of mercury in the environment. This is due in part to chloride's abundance and persistence, and the low affinity of mercury chloride complexes for soil surfaces. It is possible that other ligands, particularly other halides, could also cause a significant increase in mercury mobility. Because mercury concentration is positively correlated to dissolved organic carbon, mercury may also be bound to humic and fulvic acids in soil pore water.

Mercury may also be re-mobilized through the microbial reduction of Hg^{2+} to the more volatile elemental mercury (Hg^0) as well as the bioconversion to volatile organic forms (dimethylmercury). Because these reactions are generally biologically mediated, temperature and pH are important considerations. For example, volatilization is generally greater in warmer weather when soil microbial activity is greatest. Volatilization is also greater in acidic soils (pH values equal to or less then 3).

Mercury in Surface Water

Most chemical analyses yield total mercury concentration for a given sample. Total mercury in water is made up principally of elemental mercury, dissolved complexes of methylmercury and mercuric ion, and particulate forms of methylmercury and mercuric ion. Total mercury is a poor predictor of mercury speciation. For example, methylmercury as a percent of total mercury in water ranges from a few percent to more than 60 percent and is not solely a function of total mercury concentrations in water.

- Mercury participates in a dynamic biogeochemical cycle in aquatic environments.
- In aquatic environments having a pH range typical of environment conditions, the formation of mercuric sulfide (HgS) is favored. Mercuric sulfide precipitates out of solution, thus removing mercury from the water column.
- Dissolved-phase mercuric complexes ($HgCl_2$) are important in the water column as they increase mobility.
- Ionic mercury can be reduced to elemental mercury. Once formed, elemental mercury can volatilize, thereby reducing the dissolved phase mercury burden.
- Ionic mercury can also be methylated to form methylmercury. This reaction is especially prevalent under anoxic conditions. Methylmercury tends to accumulate in the underlying sediments, also decreasing the dissolved phase mercury burden.

Water samples collected from lakes and rivers in the Ottawa, Ontario, region of Canada had total mercury concentrations ranging from 3.5 to 11.4 ng/L, with organic mercury concentrations ranging from 22 to 37 percent. Higher concentrations were measured in water samples collected from Crab Orchard Lake in Illinois and from surface waters of lakes and rivers in California. Specifically, mercury measurements ranged from 70 to 281 ng/L for the Illinois samples and from 0.5 to 104.3 ng/L for the California samples.

Reactions with particulates dominate the fate of mercury in aquatic environments. In surface waters having an average concentration of sulfide, mercury will form mercuric sulfide (HgS) at pH ranges of 4 to 9. This compound is relatively insoluble in aqueous solutions and will precipitate out. Under acidic conditions, the activity of the sulfide ion decreases and the formation of mercuric sulfide is inhibited. Under these conditions, the formation of methylmercury is favored instead. The formation of mercuric sulfide and the adsorption of mercury to particles result in a significant fraction of mercury settling to the bottom sediments.

Mercury can exist in surface water as both the mercuric (Hg^{2+}) and mercurous (Hg^+) states. Because mercurous mercury is unstable, mercuric mercury is the predominant form of the two. Under environmental conditions, mercuric ion forms dissolved organic and inorganic complexes in the water column.

Mercuric ion can be transformed by biological and/or photo-chemical reduction to elemental mercury (Hg^0) or by biological methylation to methylmercury (CH_3Hg^+). Once formed, elemental mercury can volatilize to the atmosphere, whereas methylmercury can be accumulated in the underlying sediments or bioaccumulated in the food web. These reactions are reversible, and mercuric ion can also result from the oxidation of elemental mercury or the demethylation of methylmercury.

Reduction of Hg^{2+} to Hg^0 can occur under both aerobic and anaerobic conditions. It is enhanced by light and inhibited by competition from chloride ions. Surface waters may be saturated with volatile elemental mercury at times; however, production is seasonal and the highest levels generally occur during the warmer summer months. The exchange of elemental mercury with the atmosphere can lower the surface water mercury burdens

Because of methylmercury's toxicity and tendency to bioaccumulate, it is a very important species of mercury. While some evidence for abiotic methylation exists, mercury methylation in the environment is mediated principally by sulfate-reducing bacteria that occur in freshwater and marine sediments. High rates of methylation have been observed in anoxic sediment and water, and at the thermocline of the stratified lakes and estuaries.

As a biologically mediated reaction, methylmercury formation is sensitive to factors that affect biological activity as well as the physicochemical factors that govern the availability of inorganic mercury. The most important of these factors are dissolved oxygen concentration, temperature, lake basin characteristics (e.g., depth, water retention time), pH, sulfate and sulfide concentration, chloride concentration, water hardness, biological productivity, and total mercury concentration. Methylmercury production generally increases under conditions of elevated temperature and reduced dissolved oxygen concentration. In the anoxic hypolimnion of seasonally stratified lakes, methylmercury has been observed to accumulate at levels greater than 10 ng/L. This buildup has been related to *in situ* methylmercury production and re-mobilization from particulate matter.

<u>*Mercury in Sediments*</u>

Mercury levels in surface sediments of the St. Louis River range from 18 to 500 ng/L. Mercury was detected in sediment samples from Crab Orchard Lake in Illinois at greater then 60 Fg/L. Surficial sediment samples from several sites along the Upper Connecting Channels of the Great Lakes had mercury concentrations ranging from below the detection limit to 55.80 Fg/g. Mercury concentrations were correlated with particle size fractions and organic matter content.

- C Inorganic mercury tends to sorb to particulate matter and settle out. Inorganic mercury is not readily desorbed and the sediments are an important sink for both freshwater and estuarine systems.
- C Sediments are also considered to be a sink for methylmercury; however, methylmercury may be released back into the water column under anaerobic/sulfidic conditions.

The dominant process controlling the distribution of mercury compounds in the environment appears to be the sorption of non-volatile forms to soil and sediment particulates, which settle out of the water column with little resuspension from the sediments back into the water column. Inorganic mercury sorbed to particulate material is not readily desorbed. Thus, sediments are an important repository for inorganic forms of mercury. Sediments tend to be a reservoir for mercury in both freshwater and estuarine systems.

Sediments generally are also considered to be a sink for methylmercury. In contrast to inorganic mercury, however, methylmercury may be released back into the water column under anaerobic/sulfidic conditions. Specifically, methylation is favored under anaerobic conditions, whereas demethylation is favored in oxic waters.

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystems

Acute toxicity in the aquatic community for inorganic mercury ranges from 5 to 10 µg/L and 155 to 440 µg/L for aquatic invertebrates and fish, respectively. In contrast, for organic mercury, acute toxicity have documented to range from 5.0 to 65 µg/L for yearling brook trout and for invertebrates acute effects have ranged from 0.9 to 3.2 µg/L. In both organic and inorganic mercury, acute effects in fish included behavioral changes and lethality. For chronic effects, concentration at 0.04 µg/L and 0.79 µg/L reduced the growth of rainbow trout and brook trout, respectively (Eisler, 1987). Acute effect levels (LC_{50}s) to amphibians are observed at concentration ranges from 0.01 to 107 mg /L depending on the species exposed and the duration of exposure. Developmental effects to amphibian embryos were indicated at concentrations ranging from 0.002 to 0.37 mg/L (Power et al., 1989; U.S. EPA, 1996b). Given the observed levels of acute and chronic toxicity in amphibian species, amphibians are likely to demonstrate similar sensitivities as indicated in fish populations (Figure 1).

Terrestrial Ecosystems

Among mercury species, methylmercury is the most toxic to mammals. Daily doses of methyl mercury ranging from 0.1 to 0.5 mg/kg-day or 1.0 to 5.0 mg/kg diet were lethal to sensitive mammals (Eisler, 1987). Central nervous system toxicity, weight loss, and mortality were observed among rats fed a diet containing 250 mg/kg methylmercury for 2 weeks (Verschuuren et al., 1976a). Rats consuming 2.5 mg/kg methylmercury in the diet for 2 years displayed adverse impacts to growth and physiological functions (Verschuuren et al., 1976b). No adverse effects to reproductive endpoints were observed in rats fed at 0.5 mg/kg and below over a three generation experiment, but at 2.5 mg/kg, offspring survival rate was reduced.

For birds, acute toxicity for methylmercury ranges from 2.2 to 23.5 mg/kg for mallard (*Anas platyrhynchos*), 11.0 to 27.0 mg/kg diet for Japanese quail *(Coturnix japonica*), and 37.9 mg/kg for whistling duck (*Dendrocygna bicolor*). Heinz (1979) fed mallard ducks a diet containing 0.5 mg/kg methylmercury for three generations. Although it did not affect adult weights or weight changes, for those female birds exposed to methylmercury, decrease in clutch number, egg shell thickness, and behavioral modifications in young were noted.

Plants, algae, and soil invertebrates appear more resistant to mercury exposure than other receptors (Figure 1). A few studies have been conducted to characterize the toxicity of mercury in terrestrial plants by measuring growth endpoints. No effects levels were indicated at concentrations of 35 mg Hg/kg soil, but reduced growth was observed at 64 mg Hg/kg soil

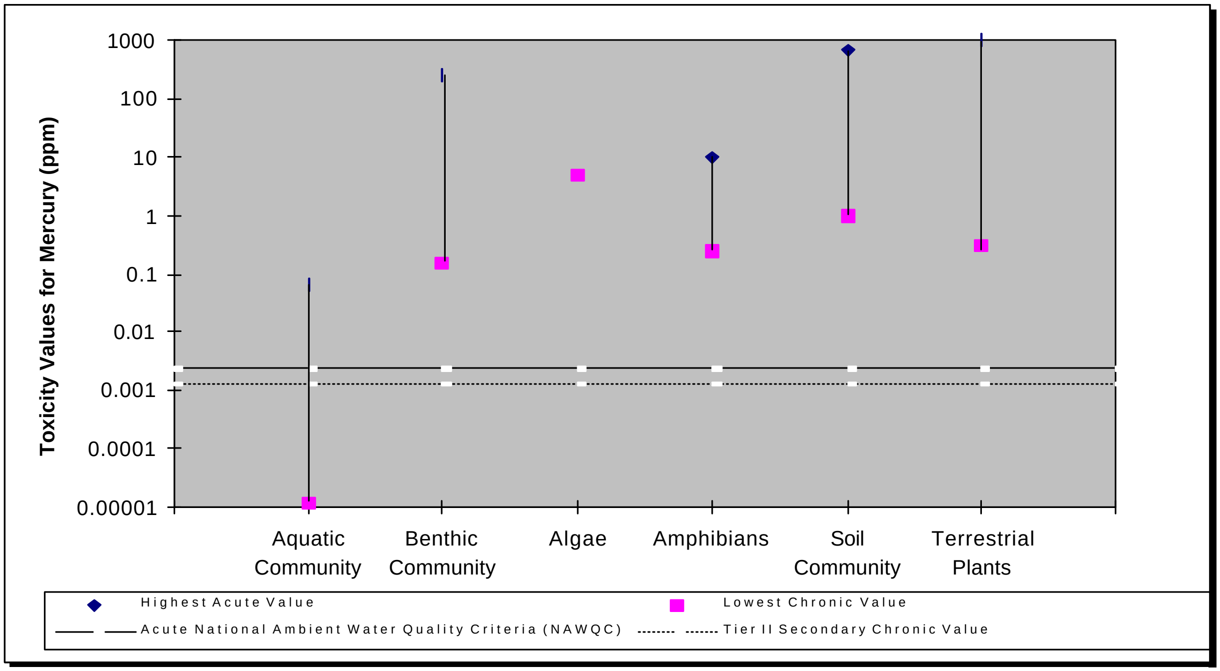

Figure 9: Mercury: Effects Ranges for Ecological Receptors

(Efroymson et al., 1997a). In soil invertebrates, effects to earthworm survival, cocoon production, and segment regeneration were indicated in the range of 0.5 to 12.5 mg Hg/kg soil following chronic exposures over sixty days (Efroymson et al., 1997b).

IV. Bioaccumulation Potential

Freshwater Ecosystems

The bioaccumulative capacity of mercury, as methyl mercury, in fish is key to exposure resulting in adverse effects to organisms consuming aquatic species. Studies have indicated that mercury bioaccumulates in aquatic systems. In phytoplankton, bioconcentration factors (BCFs) have been reported to range from 100,880 to 477,300; and in zooplankton, BCFs ranges from 35,600 to 1,000,000 (US EPA, 1996a). BAFs in fish, the *Mercury Study Report to Congress* (US EPA, 1996) represents the state-of-the-science approach in estimating the bioaccumulation factors (BAFs) for mercury; therefore, the BAF values of 335,000 for trophic level 4 fish and BAF value of 66,200 for trophic level 3 (BAF_3) fish presented in the report were used in estimating the food chain exposure of piscivorus mammals and birds. The following subsection briefly describes the methods used by EPA in deriving the BAFs for fish.

- **Derivation of BAF for Trophic Level 3 fish (BAF_3)**

  Trophic level 3 BAF for methylmercury is 66,200. This is a semi-empirical value from statistically fitting 10 field data to a lognormal distribution. The mean of this distribution is selected as BAF_3.

• Derivation of Predator-Prey Factor (PPF_4)

Predator-prey factor (ratio of concentration of methylmercury in predator fish to that of the concentration of methylmercury in forage fish) was derived (calculated) has a value of about 5.0. It reflects the increase in methylmercury concentration from lower trophic level to a higher trophic level predator fish. The mean PPF_4 is generated using Monte Carlo simulation[1] based on a beta distribution 17 data points, ranging from 1.2 to 15.1.

• Derivation of BAF for Trophic Level 4 fish (BAF_4)

The inputs parameters used to calculate BAF_4 is as follows:

$$BAF_4 = BAF_3 \times PPF_4$$

BAF_3 is the bioaccumulation factor for trophic level 3. As described previously it has a mean value of 66,200 with a lognormal distribution. PPF_4 is the predator-prey factor for trophic level 4. It has an approximate mean value of 5.0 with a beta distribution. BAF_3 and PPF_4 are sampled randomly according to the statistical parameters of those two inputs and the product of those two randomly selected values is considered a

possible value for BAF_4. This resampling method is iterated 20,000 times to generate a distribution of BAF_4 values.

Table A. BAF_4 Calculations Using Monte Carlo Simulations*

Statistic	BAF_4
Mean	335,000
Standard deviation	5.053
Percentile	
5th	22,700
25th	111,000
50th	336,000
75th	1,000,000
95th	4,700,000

*from US EPA, 1996

The percentiles of the resulting BAF_4 distribution represent the likelihood of that a given piscivorus fish will exhibit such a BAF, and the geometric mean of this result is taken as the BAF_4 (US EPA, 1996). The BAFs generated from the above methodology were used to derived protective media concentrations in water for mammalian and avian receptors.

[1]Monte Carlo simulations is a resampling technique frequently used in uncertainty analysis in risk assessment. In practice, distributions are assigned to input parameters in a model and the model is recalculated many times (typically 10,000 iterations) to produce a distribution of output parameters (e.g. estimates of BAF_4). Each time the model is recalculated, a value is selected from within the distribution assigned for each input parameter. As a result, distribution of BAF estimates is produced that reflects the variability of the input parameters.

Terrestrial Ecosystems
Bioaccumulation in terrestrial invertebrates, plants, and small mammals is currently being investigated at Oak Ridge National Labs. Bioaccumulation and bioconcentration factors (BAFs and BCFs) for terrestrial plants, invertebrates, and small mammals have been proposed from review of primary literature sources. The 90th percentile of the bioaccumulation data for these receptors derived from both laboratory and field studies were used to determine terrestrial food chain exposures. For earthworms, a BAF of 21 was proposed for mercury based on 30 data points. For terrestrial plants there was no proposed BCF. For small mammals, based on 18 reported values assessing the transfer of mercury from soil to small mammals, a BAF of 0.19 was proposed (Sample et al., 1997; Samples et al., 1998). These values were used to model food chain exposures to terrestrial species for this analysis, because currently, they stand as the most comprehensive collection of bioaccumulation data for terrestrial ecological receptors (Sample et al., 1997; 1998a; 1998b).

V. CSCL Development

The benchmark values presented in this section for mammals and birds were used to derive protective media-specific CSCLs as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor and the potential bioconcentration in prey, a protective concentration (i.e., CSCLs) in soil, plants or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. By protecting the more sensitive species, other receptors are likely to be protected as well.

Mammals: Two subchronic studies were identified which reported dose-response data for mammalian wildlife. Rhesus monkeys were exposed to methylmercury chloride by gavage at doses of 0.05. 0.16 or 0.5 mg/kg-day during gestation days 20 through 30. No signs of malformation were seen at the two lower doses (Dougherty et al. 1974). However, the highest dose level was maternally toxic and abortient, suggesting a NOAEL of 0.16 mg/kg-day and a LOAEL of 0.5 mg/kg-day for reproductive effects.

A second study fed adult female mink containing methylmercury chloride at doses of fed adult female mink rations containing methylmercury chloride at doses of 0.18, 0.29, 0.77, 1.3 and 2.4 mg/kg-day (Wobeser et al. 1976a and 1976b). Groups exposed to doses of 0.29 - 2.4 mg/kg-day exhibited clinical signs of toxicity. The 0.18 mg/kg-day exposure group did not show clinical evidence of toxicity but did exhibit pathological alterations of the nervous system. The authors stated that clinical signs of toxicity in the 0.18 mg/kg-day exposure group would have probably emerged if the experiment had lasted longer. A LOAEL of 0.18 mg/kg-day was inferred for pathological alterations from this study. The NOAEL derived from this study was 0.055 mg/kg-day (U.S. EPA, 1996).

The NOAEL from the Wobeser et al. (1976a and 1976b) study was selected to derive the toxicological benchmark because: (1) doses were administered over a chronic duration and via oral ingestion, an ecologically significant exposure pathway; (2) the study focused on toxicity endpoints that could impact the reproductive potential of a species; and (3) it contained adequate dose-response information. The Dougherty et al. 1974 was also an adequate study for selection; however, the premier source of information on mercury's risk to ecological receptors (*Mercury Study Report to Congress* U.S. EPA, 1996) considered the Wobester et al. (1976a and 1976b) to be a more appropriate benchmark study for CSCLs derviation.

Birds: Several studies were identified which investigated the effects of methylmercury on avian species. In a series of studies carried over three generations, Heinz (1974, 1975, 1976a, 1976b, 1979) assessed the effects of dietary methylmercury on mallard ducks. Adult mallard ducks given doses of 0.064 and 0.384 mg/kg-day for up to 2 years were monitored for egg production, hatching success and hatchling viability. Based on an assessment of percent cracked eggs, egg production or number of eggs producing normal hatchlings, no significant reproductive effects were observed in the first generation. However, the survival rate of offspring from the 0.384 mg/kg-day treatment group was significantly lower. Second generation parents on the 0.064 mg/kg-day diet exhibited abnormal egg-laying behavior, impaired reproduction and their ducklings had a slowed growth rate. Third generation hens in the 0.064 mg/kg-day treatment group laid fewer viable eggs than those in the control group. Behavior tests designed to measure approach response to maternal calls and avoidance response to a frightening stimulus pooled over three generations indicate the cumulative effects over three generations were significant at the lowest dose level. Therefore, a LOAEL of 0.064 mg/kg-day was inferred based on adverse reproductive and behavioral effects across the three generations of mallard ducks; and a NOAEL is extrapolated by a factor of 10 to arrive at a value of 0.0064 mg/kg-day.

Ring-necked pheasants were exposed to dietary methylmercury at doses equivalent to 0.18, 0.37, and 0.69 mg/kg-day for 12 weeks (Fimreite, 1970). Reduced hatchability and egg production as well as increased numbers of shell-less eggs were reported at all dose levels. Based on these results, a LOAEL of 0.18 mg/kg-day can be inferred for reproductive effects. In another study by Fimreite (U.S. EPA, 1993b), leghorn cockerel chicks were exposed to dietary methylmercury at concentrations of 1.1, 2.1, and 3.2 mg/kg-day for 21 days. A significant increase in mortality occurred at exposure to 3.2 mg/kg-day while chicks maintained at 2.1 mg/kg-day exhibited decreases in growth. Although this study reports a NOAEL of 2.1 mg/kg-day for mortality and a LOAEL of 1.1 for growth, it is unclear as to whether these exposure levels would affect an entire population's survival. Reproductive effects were seen in white leghorn laying hens when they were exposed to methylmercury at dietary concentrations of 4.9 and 9.8 mg/kg-day for an unspecified period of time (Scott, 1977). Both dose levels severely impacted egg production and weight, fertility of eggs, hatchability of fertile eggs, and eggshell strength.

Although the studies by Fimreite (1971) and Scott (1970) provide reproductive endpoints in response to multiple, dietary methylmercury dose levels, the results of the Heinz (1974, 1975, 1976a, 1976b, 1979) multigeneration studies were found to be most appropriate for the estimation of a benchmark value for avian species. These studies provide reproductive and behavioral effects due to methylmercury exposure over three generations of mallards. From all the avian studies identified, Heinz (1974, 1975, 1976a, 1976b, 1979) furnished the most conservative dose level that could impair the survival and reproductive potential of an avian population. Therefore, the LOAEL of 0.064 mg/kg-day was used to derive a benchmark value for representative avian species of the freshwater ecosystem.

The LOAEL value from the Heinz (1974, 1975, 1976a, 1976b, 1979) was then scaled for species representative of a freshwater ecosystem using a cross-species scaling algorithm adapted from

Opresko et al. (1994). This is the same default methodology EPA provided for carcinogenicity assessments and reportable quantity documents for adjusting animal data to an equivalent human dose (57 FR 24152). Since Heinz (1974, 1975, 1976a, 1976b, 1979) documented reproductive effects from methylmercury exposure to both male and female mallards, the body weights of both male and female representative species were used in the scaling algorithm to obtain toxicological benchmarks.

Data were available on reproductive, developmental, growth and survival endpoints for methylmercury exposure. In addition, the data set contained studies which were conducted over acute and chronic durations and during sensitive life stages. Other than the studies discussed for the freshwater ecosystem, no avian toxicity data were identified. Therefore, the NOAEL of 6.40E-03 mg/kg-day extrapolated from Heinz (1974, 1975, 1976a, 1976b, 1979) was chosen to calculate a benchmark value for the representative avian species in the terrestrial ecosystem.

Freshwater Community: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria (NAWQC) published by the EPA Office of Water. The FCV of 9.1E-04 mg/L for mercury (II) developed under the GLWQI was used. The GLWQI values were considered preferable to the NAWQC because: (1) the GLWQI values are based on the same methodology used to develop NAWQC (i.e., Stephan et al., 1985); (2) the NAWQC data set was augmented with previously unavailable acute and chronic toxicity data; and (3) species taxa used to generate the GLWQI values are suitable for national application since they include species and taxa found throughout the United States.

Sufficient data were not available to develop an FCV for methyl mercury, rather a Secondary Chronic Value (FCV) of 2.8E-06 mg/L for methyl mercury developed by Oak Ridge National Laboratory (Suter and Tsao, 1996) was selected as the appropriate criteria to use in this analysis. SCVs are calculated by analogous methods used to derived FCVs for both the GLWQI and NAWQC. However, when the eight data requirements for developing the FCV were not available, the FCV criteria was based on one to seven of the eight required criteria. The FCV for methyl mercury was derived from 4 data points based on toxicity endpoints found in rainbow trout (*Oncorhynchus mykiss*) and brook trout (*Salvelinus fontinalis*). From these data, an SAV of 9.917E-5 mg/L and SACR of 35.72 were calculated. The resulting ratio of these values (i.e., SAV/SACR) determined the FCV of 2.8E-6 mg/L (Suter and Tsao, 1996).

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metals concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). Consequently, the FCVs can be adjusted to provide dissolved concentrations as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*); however, a CF was not available for mercury or methyl mercury. This adjustment (i.e., use of conversion factors) reflects the current Agency position on criteria development and regulatory application of metals; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). For example, the relationship between water characteristics (e.g., dissolved organic matter), copper bioavailability, and toxicity has been investigated in some detail (e.g., Allen and Hansen, 1996). Aquatic CSCLs developed in this section are summarized in Table 1.

Amphibians: No suitable subchronic or chronic studies were identified which studied the effects of mercury toxicity on reproductive or developmental endpoints in amphibian species; however, several acute studies were identified characterizing mercury toxicity. Review of data collected from sixty-seven experiments indicate that the acute toxicity of mercury ranges from 0.001 to 108 mg mercury/L, with a geometric mean of 0.20 mg/L. Acute studies were conducted on various amphibian species (i.e., twenty-seven amphibian species represented) during embryo, tadpole, and adult lifestages. Chemical exposures were conducted primarily with mercuric chloride (Hg^{2+}). The observation that the lowest acute amphibian value approximates the FAV of 0.0024 mg mercury/L determined for the freshwater community indicates that some amphibian species may be sufficiently protected from acute effects by the current acute freshwater criteria. A few chronic exposures were identified indicating deformity from 96 hour exposures to 0.0001 to 0.1 mg Hg/L depending on the species. Longer exposures of 7 to 10 days indicate deformities at concentrations of 0.0003 to 0.08 mg mercury/L at varying degrees of severity and magnitude. Further, spermatogenesis was inhibited at concentrations of 0.3 mg mercury/L. Given the limited number of studies and the lack of consistency (e.g., endpoints and test protocols) in chronic amphibian data, a CSCL of 0.20 mg mercury/L was derived based on acute toxicity. Since the CSCL is based on acute data (i.e., lethality), the severity of the potential adverse effects that this CSCL indicates should be noted. Investigations are ongoing to review the possibility of incorporating amphibian data into the NAWQC. Since amphibian species are more likely to breed in standing waters such as wetlands or ponds, the appropriateness of combining protective levels of amphibian receptors and the freshwater community is unclear at this time (Power et al.,1989; U.S. EPA, 1996).

Algae and Aquatic plants: The toxicological CSCLs for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or (2) an effective concentration (EC_{xx}) for species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). For mercury the CSCL value was determined to be 5.0E-03 mg/L based on the growth inhibition of *Microcystis aeruginosa*. Low confidence is placed in this CSCL since it is only based on one study (Suter and Tsao, 1996).

Benthic Community- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, CSCLs are developed estimating the 10th percentile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). These values are not NOAA standards; rather, they are used to rank sites based on the potential for adverse ecological effects. A second criteria document evaluated for sediment criteria development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the criteria was changed. FDEP calculated the criteria (i.e., threshold effects level, TEL) from the geometric mean of the 50^{th} percentile of no effects data and the 15^{th} percentile of the low effects data. The NOAA data, used in both documents, is based on total metal concentrations in sediments, and the toxicity endpoints were measured on species of amphipods, arthropods, and bivalves in addition to a variety of community-based endpoints (e.g., abundance, mortality, species composition, species richness). The FDEP criterion was chosen above the NOAA criterion for the following reasons; (1) the same database was used for both the NOAA criteria and the FDEP criteria development only different derivation methods were used; (2) in most cases, the FDEP criterion was more conservative than the NOAA criteria because a larger portion of the low effects data was used in CSCL development; (3) the marine TEL developed by the FDEP were found to be analogous to TELs observed in freshwater organisms (Smith et al., 1995).

The CSCL for mercury was derived from 331 toxicity data points for low and no effects levels. For the screening level analysis of mercury, the TEL of 1.3E-01 mg mercury/kg sediment was selected as an appropriate sediment CSCL. Based on the quality and quantity of mercury sediment data, the degree of confidence in the TEL value for mercury was considered high (MacDonald, 1994).

Terrestrial Plants: As presented in Efroymson et al. (1997a), phytotoxicity CSCLs were selected by rank ordering the lowest observable effects concentration (LOEC) values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the CSCL. Such LOECs applied to reductions in plant growth, yield, or seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. The proposed CSCL for phytotoxic effects of mercury in soils is 0.3 mg mercury/kg soil (Efroymson et al, 1997a). Since the CSCL was based on a single study reporting unspecified effects and did not indicate the form of mercury applied to test soils or the terrestrial plant species exposed, this CSCL study was not appropriate for CSCL development. No further studies were identified, so no CSCLs could be developed for the terrestrial plant community.

Soil Community: A soil CSCL was derived from the criteria proposed by ORNL (Efroymson et al., 1997b) (1996) . The proposed CSCL of 1.0E-01 mg total mercury/kg soil was the lowest toxicity value based on earthworm endpoints. Additionally, a microbial toxicity value was identified to be 30 mg total mercury/kg soil. Value based on earthworm was proposed as the CSCL because earthworm is an important component in promoting soil fertility, improve aeration, drainage of soil, and serve as an important food source for many higher trophic animals. Community-based CSCL values should be used as they become available. Low confidence is placed in this CSCL because of the lack of supporting data.

Table 1. Mercury CSCLs in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Mammals	2.8E-07	mg/L water	Food web	River Otter	Wobeser et al., 1976a,b; U.S. EPA, 1996a
Birds	1.9E-07	mg/L water	Food web	Kingfisher	Heinz, 1974; 1975; 1979; U.S. EPA, 1996a
Algae and Aquatic Plants	5.0E-03	mg/L water	Direct contact	*Microcystis aeruginosa*	Suter and Tsao, 1996
Freshwater Community					
Mercury (II)	9.1E-04	mg/L water	Direct contact		U.S. EPA, 1995a
Methyl mercury	2.8E-06	mg/L water	Direct contact	Aquatic biota	Suter and Tsao, 1996
Benthic Community	1.3E-01	mg/kg sediment	Direct contact	Aquatic biota	MacDonald, 1994
Amphibians (acute effects)	2.0E-01	mg/L water	Direct contact	Benthos	Power et al., 1989; U.S. EPA, 1996
				Various amphibian species	
Terrestrial					
Mammals	3.8E+01	mg/kg soil	Food web	Raccoon	Wobeser et al., 1976a,b
Birds	1.5E-01	mg/kg soil	Food web	American woodcock	Heinz, 1974; 1975; 1979
Mammals	2.0E+00	mg/kg plant	Food web	Meadow vole	Wobeser et al., 1976a,b
Birds	1.5E-01	tissue	Food web	Northern bobwhite	Heinz, 1974; 1975; 1979
Soil Community	1.0E-01	mg/kg plant	Direct contact	Soil invertebrates	Efroymson et al., 1997b
		tissue			
		mg/kg soil			

Ecotoxicological Profile for Ecological Receptors
Molybdenum

This ecotoxicological profile on molybdenum contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (5) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of molybdenum so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

Molybdenum is a relatively rare but widespread metallic element. It is considered an essential trace nutrient for growth and development in most organisms (Eisler, 1989; IRIS, 1996, EPA, 1992-1996). High levels of molybdenum, however, are toxic to some animals, especially when copper concentrations are low. Signs of molybdenum poisoning have been found in cattle grazing on land both naturally high in molybdenum and near pollution sources. Natural background concentrations of molybdenum in soils average 1.2 mg/kg. Elevated concentrations from natural geologic processes may range approximately from 12 to 76 mg/kg. Near pollution sources, elevated concentrations within a similar range are common, although levels higher than 4,000 ppb have also been measured. Molybdenum levels in ground and surface waters are generally below 20 ppb. In contrast, contaminated waters have been found to have concentrations as high as 100,000 ppb (Eisler, 1989).

Molybdenum is found in combination with a variety of other elements, in valence states ranging from +3 through +6. The chemistry of molybdenum is complex and poorly understood; however, it is known that chemical interactions with copper and sulfur are known to affect its toxicological properties. Aquatic organisms seem to be relatively tolerant of molybdenum, except at extremely high concentrations. Resistance in other organisms varies by species. Molybdenum is bioconcentrated by terrestrial plants, sometimes to levels potentially toxic to herbivores. Bioconcentration may also be significant in some aquatic invertebrates, although in most other organisms it is minor (Eisler, 1989).

II. Geochemistry of Molybdenum in Various Ecological Media

<u>*General*</u>

> C Molybdenum may occur in the +3, +4, +5, and +6 oxidation states. However, the +6 valence state is the most important in aqueous solutions.

Molybdenum occurs naturally in ore bodies, the most important of which is molybdenite (molybdenum disulfide). Molybdenite, though seldom seen in rocks, is likely the primary source of molybdenum in nature. Upon release to the environment via natural weathering processes, molybdenum may form secondary molybdenum minerals (e.g., molybdates). Molybdenum ranges from 0.2 to 0.4 percent in ores bodies.

Molybdenum may be released to the environment via natural weathering processes or through anthropogenic activities. Chief among these activities is the production and fabrication of molybdenum products such as molybdenum steel.

Molybdenum in Soils

Molybdenum can exist in the +3, +4, +5, and +6 valence states. In aqueous solution, only the +6 state has stability over a broad range of pH and Eh conditions (EPRI, 1984). According to an Eh-pH diagram contained in Dragun (1988), molybdenum is present in the environment as two primary species, depending upon pH. Specifically, at pH values greater than 6, under both oxidizing and reducing conditions, the thermodynamically-favored species of molybdenum is the anionic MoO_4^{2-} . As the pH decreases to values equal to or less then 6, molybdenum is present as the anionic $HMoO_4^-$ under oxidizing conditions and as molybdenum oxide (MnO_2) under reducing conditions.

- Molybdenum behavior in the environment is controlled to a large extent by the pH and Eh of the system.
- At pH values greater than 6, under both oxidizing and reducing conditions, the thermodynamically-favored species of molybdenum is the anionic MoO_4^{2-}.
- At pH values equal to or less then 6, molybdenum is present as the anionic $HMoO_4^-$ under oxidizing conditions and as molybdenum oxide (MnO_2) under reducing conditions.
- The adsorption behavior of molybdenum is strongly influenced by the presence of iron and aluminum oxides.
- The principal adsorbing species is $HMoO_4^-$.
- Adsorption of MoO_4^- decreases as a function of increasing pH, and as a consequence, molybdenum mobility increases at higher pH values.
- Phosphate has been reported to be a strong competitor for molybdenum adsorption sites.

The adsorption behavior of molybdenum in soils is strongly influenced by the presence of iron and aluminum oxides over a wide range in MoO_4^{2-} concentrations (EPRI, 1984). Amorphous aluminosilicates (e.g., allophane) also have high affinity for molybdenum. Available information suggests that the principal adsorbing species is $HMoO_4^-$. Though a mechanism has not been established, soil organic matter has also been proposed as an important factor in controlling adsorption from aqueous solutions containing low concentrations of molybdenum.

Solution pH and ionic strength may strongly influence molybdenum adsorption (EPRI, 1984). Adsorption of MoO_4^- decreases as a function of increasing pH. This is attributed to increasing negative charge density on amphorteric hydrous oxides or functional groups. This phenomenon is comparable to that observed for other anions where a marked adsorption edge is observed for molybdenum on model adsorbents, specifically hydrous oxides.

The presence of certain competing anions and soil-saturating cations also influences molybdenum adsorption. Although increasing solution concentrations of poorly or weakly adsorbed anions (e.g., Cl^- or SO_4^{2-}) do not affect molybdenum retention; the presence of PO_4^{3-}, which is strongly adsorbed, may decrease molybdate adsorption. Additionally, phosphate readily displaces freshly-adsorbed MoO_4^{2-}.

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystems

Molybdenum appears to be fairly non-toxic to many aquatic organisms. Acute, adverse effects on growth and survival in aquatic invertebrates and fishes has been found mostly only at very high molybdenum concentrations (60 mg/L and higher) (Mo^{6+}). Hamilton and Buhl (1990) exposed chinook and coho salmon at varying life stages to molybdenum in fresh, brackish, and soft waters, and found no mortalities or visible signs of stress even at the highest exposure level of 1,000 mg/L (Mo^{6+}). However, when newly fertilized eggs of rainbow trout were exposed for 28 days, the LC_{50} value was only 0.79 mg/L (Mo^{6+}) (Eisler, 1989). McConnell (1977) also exposed juvenile rainbow trout to molybdenum concentrations as high as 17 mg/L for one year (Na_2MoO_4; Mo^{6+}), and found no significant differences in growth, or mortality compared to controls.

Although aquatic plants require molybdenum in small amounts for normal growth, adverse effects on growth and on development in sensitive species have been found at 50 mg/L and 108 mg/L, respectively (chemical form unspecified). Freshwater plants may accumulate up to 20 mg/kg dry weight without ostensible harm. The effects on animals of consuming such plant material, however, are not known (Eisler, 1989).

Terrestrial Ecosystems

Although there are few data on the effects of molybdenum on wildlife animals, its toxicity to livestock and laboratory mammals have been studied. In many cases, a low copper:molybdenum ratio in the diet has been found to be more important in determining toxicity than the absolute concentration of molybdenum alone (Eisler, 1989). The wide range of chronic effects includes survival, growth, and reduced reproduction. Reproductive effects such as testicular damage male sterility (Jeter and Davis, 1954; U.S. EPA, 1990d), increased incidence of resorbed fetuses, decreased fertility, and poor lactation in females have been observed (Jeter and Davis, 1954; Schroeder and Mitchener, 1971b; Fungwe et al., 1990; U.S. EPA, 1990d). Damage to liver, kidney, bone, and connective tissue has been observed in rabbits, sheep, and rats (Arrington and Davis, 1953; Pitt et al., 1980). Molybdenum toxicity can be mitigated by dietary factors, especially copper intake (e.g., U.S. EPA, 1990d; Jeter and Davis, 1954). Some symptoms related to molybdenum toxicity have been rapidly relieved by treatment with copper (Arrington and Davis, 1953).

Birds are relatively resistant to the toxic effects of molybdenum; symptoms of molybdenum deficiency and benefits of dietary molybdenum supplements have been reported for chickens and

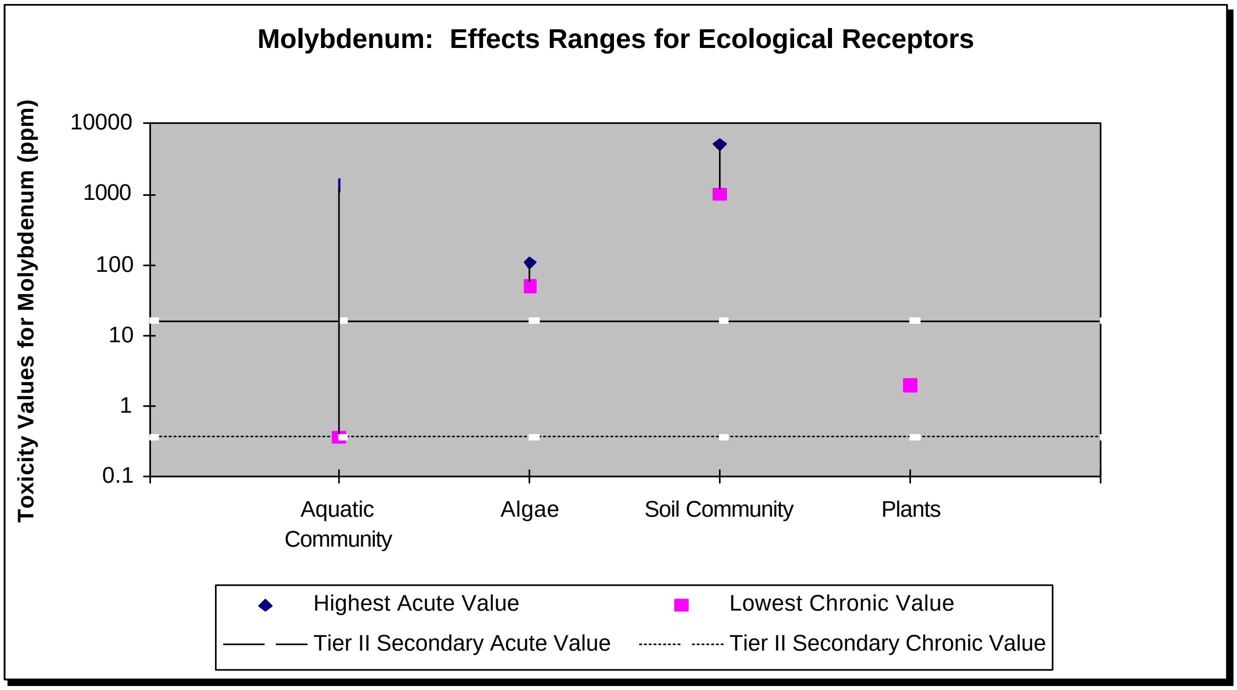

Figure 10: Molybdenum: Effects Range for Selected Ecological Receptors

turkeys. Only at high dose levels are some effects evident (e.g. reduced growth and egg production) (Eisler, 1989).

The toxicity of molybdenum to other terrestrial organisms is variable. Termites have died after exposure to bait treated with 1,000 mg molybdenum /kg, although exposure to 5,000 mg/kg for 48 days did not affect other insects such as fire ants, cockroaches, and beetles (Eisler, 1989). Domsch (1984) reported evidence of adverse effects on the soil community, including inhibition of enzyme activity, as a result of molybdenum application. Plants usually show beneficial responses to molybdenum exposure at approximately 0.5 mg/kg soil; however, unspecified toxicity was indicated at 2 mg/kg soil (Efroymson et al., 1997a).

IV. Bioaccumulation Potential

Freshwater Ecosystems
Aquatic organisms may be exposed through contact with contaminated water or through the food chain, considering that aquatic plants may concentrate molybdenum without visible damage . Reported bioconcentration factors (BCFs) for freshwater plants range from 7 to 3,300, and apparently depend on species, exposure concentration, and exposure duration. BCFs for other aquatic organisms are generally low. A whole body BCF of 4.8 L/kg was reported for species of the amphipod *Gammarus* after 24 days of exposure to a molybdenum concentration of 3.3 mg/L. Fish BCFs such as 5.4 (spleen), 4.5 (liver), 2.3 (muscle), and 1.8 (gill) (all in L/kg) were reported in steelhead trout after 24 days of exposure to a molybdenum concentration of 3.3 mg/L (Eisler, 1989). However, sufficient data to determine whole-body fish BCF values were not identified.

Terrestrial Ecosystems
Molybdenum is essential for plant growth; and plants readily accumulate molybdate under most

conditions. Molybdenum adsorbed onto airborne particles could enter the terrestrial ecosystem either directly by atmospheric deposition or indirectly from water. In soils molybdate has been found to adsorb most readily to alkaline, high calcium, high chloride soils; retention was least in acidic, low sulfate soils. Plants readily accumulate molybdate, except under conditions of low pH, high sulfate, and low phosphate, and in some highly organic soils. Legumes selectively accumulate molybdenum, sometimes to potentially toxic levels. Plants grown in soil with high concentrations may contain elevated levels of the metal. Concentrations of greater than 20 mg/kg dry weight have frequently been observed in plants from polluted areas. Toxicity of molybdenum in field-grown crops has not been observed, though forages containing 10 to 20 mg/kg dry weight are considered toxic to cattle and sheep (Eisler, 1989). Pitt et al. (1980) reported toxic effects in sheep that grazed on treated pasture, with molybdenum concentrations ranging from 5.5 to 12.5 mg/kg dry weight. Therefore, the food chain would probably be the dominant route of exposure to any herbivore. Exposure to water soluble forms of molybdenum such as molybdate would also be possible through drinking water. Molybdenum concentrations measured in a wide variety organisms, including birds, domestic ruminants, and mammalian wildlife, were generally low, with the notable exception of terrestrial plants (Eisler, 1989), suggesting that bioconcentration in organisms other than plants is probably minor. Sufficient data, however, were not identified to determine bioconcentration factors (BCFs) for terrestrial vertebrates or terrestrial invertebrates, plants, and earthworms.

V. CSCL Development

The benchmark values presented in this section for mammals and birds were used to derive protective media-specific CSCL as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor and the potential bioconcentration in prey, a protective concentration (i.e., CSCLs) in soil, plants or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. It is assumed that by protecting the more sensitive species, the other receptors are protected as well.

Mammals: Numerous studies were identified which investigated molybdenum-induced toxicity in mammalian species. Fungwe et al. (1990) exposed female weanling rats to molybdenum in drinking water at doses of 5, 10, 50 or 100 mg/L. The exposure period extended from six weeks prior to mating through day 21 of gestation. No signs of toxicity were observed in rats given 5 mg/L; however, those given 10 mg/L exhibited lower gestational weight gain, an increased incidence of resorbed fetuses and sites of resorption, and a decrease in average litter size. A NOAEL of 5 mg/L and a LOAEL of 10 mg/L were inferred for fetotoxic effects. Conversion of these doses in units of mg/L to daily doses in units of mg/kg-day required reference estimates of body weight (0.107 kg) and water intake in female Sprague-Dawley rats (0.019 L/day) (U.S. EPA, 1988a). The resulting NOAEL is 0.89 mg/kg-day, and the LOAEL is 1.78 mg/kg-day. The study by Fungwe et al. (1990) was considered the most suitable for derivation of a mammalian toxicological benchmark because:(1) it established a dose-response relationship; (2) it focused on reproductive or fetotoxic endpoints; (3) it resulted in the most conservative NOAEL in the data set; and (4) it administered doses via oral ingestion, an ecologically significant exposure pathway.

Several other studies were selected for discussion. In a multi-generational study, Schroeder and Mitchener (1971b) exposed mice orally to 10 ppm molybdenum in drinking water for three generations. Reproductive and fetotoxic effects exhibited by the third generation included decreased fertility in the mating pairs, increased incidence of dead litters, and increased incidence of early deaths. Since only one dose was used for this study, an AEL of 10 ppm was inferred for reproductive and fetotoxic effects. Using a reference water consumption rate for mice of 0.006 L/day and a reference body weight of 0.024 kg (U.S. EPA, 1988a), the 10 ppm dose was converted to a daily dose of 2.5 mg/kg-day. In a two-part study, Arrington et al. (1965) exposed rats and rabbits to oral doses of molybdenum ranging from 500 to 2000 ppm in their feed. Although rats exposed for six weeks to 500 ppm showed no signs of clinical toxicity, those given 1000 ppm had reduced voluntary feed intake and decreases in growth and feed utilization efficiency. Based on these results, a NOAEL of 500 ppm (or 6.0 mg/day, reported in the study) and a LOAEL of 1000 ppm (or 9.3 mg/day) were inferred for growth effects in rats. Rabbits exposed for three weeks to 2000 ppm exhibited similar signs of toxicity, including reduced voluntary feed intake and growth while those rabbits given 1000 ppm showed no adverse effects. A NOAEL of 1000 ppm (or 67 mg/day) and a LOAEL of 2000 ppm (or 88 mg/day) were inferred for pathological effects of molybdenum in rabbits. Conversion of these doses to daily doses in units of mg/kg-day required estimates of body weights for Long-Evans rats (0.126 kg) and Dutch and New Zealand rabbits (2.49 kg) (U.S. EPA, 1988a). The resulting daily doses are a NOAEL of 48 mg/kg-day and a LOAEL of 74 mg/kg-day for rats, and a NOAEL of 27 mg/kg-day and a LOAEL of 35 mg/kg-day for rabbits. Although the Schroeder and Mitchener (1971b) study investigated reproductive effects of molybdenum exposure in mice, it was not considered suitable for the derivation of a benchmark value because only a single dose was administered, and, therefore, a dose-response relationship was not established. The Arrington et al. (1965) study does provide a dose-response relationship for molybdenum toxicity in rats and rabbits; however, the toxicological endpoints do not clearly indicate that a wildlife population's fecundity would be impaired.

Since no additional mammalian toxicity studies were identified, the Fungwe et al. (1990) study used for the freshwater ecosystem was also used to calculate a mammalian benchmark value for species in the terrestrial ecosystem.

Birds: Study done by Lepore and Miller (1965) (as cited by Sample et al., 1996) were used to derive CSCLs for birds. They examined molybdenum's effects on the reproduction of chickens with a diet of 500, 1000, and 2000 ppm. Chickens that were treated with 500 ppm reduced its reproductive capability. As reported by Sample et al. (1996), the LOAEL for chicken is 35.3 mg/kg-day and the NOAEL is 3.5 mg/kg-day. Additional avian toxicity data were not identified for birds representing the terrestrial ecosystem. Therefore, the study used for freshwater ecosystem was also used to calculate terrestrial avian CSCLs values.

Freshwater Community: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria (NAWQC) published by the EPA Office of Water. Neither of these criteria have been developed for molybdenum; therefore, a Secondary Chronic Value (SCV) was calculated. SCVs are calculated by analogous methods used to derived FCVs for both the GLWQI and NAWQC. However, when the eight data requirements for developing the FCV were not available, the SCV criteria was based on one to seven of the eight required criteria. For molybdenum, the SCV of 3.7E-01 mg/L developed by Suter and Tsao (1996) for total molybdenum was selected as the appropriate CSCL to use in this analysis. The SCV for molybdenum was derived from 4 data points derived from toxicity endpoints found in fish and aquatic invertebrates. From these data, an SAV of 15.66E mg/L and SACR of 42.26 were calculated. The resulting ratio of these values (i.e., SAV/SACR) determined the SCV of 3.7E-01 mg/L (Suter and Tsao, 1996).

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metals concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). EPA has developed conversion factors (CFs) to estimate probable dissolved concentrations of metals in surface waters given a total metal concentration as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). A CF is not yet available for molybdenum. This adjustment reflects the current Agency position on criteria development and regulatory application of metals; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). The final surface water CSCL for molybdenum is presented in Table 1.

Amphibians: No suitable subchronic, chronic, or acute studies were identified for CSCL development which studied the effects of molybdenum toxicity on reproductive, developmental, or mortality endpoints in amphibian species.

Algae and Aquatic Plants: Relevant endpoints for aquatic plants focused on the ability of plants to support higher trophic levels as well as the ability to provide habitat for other species in the freshwater ecosystem. The benchmarks for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or (2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). No Chronic Value was reported for molybdenum by Suter and Tsao (1996), and, therefore, no benchmark was developed.

Benthic Community- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, CSCLs are developed estimating the 10th per-centile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). For our purposes, the ER-L was considered an appropriate benchmark for freshwater sediment biota. A second criteria document evaluated for sediment criteria development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the criteria was changed. Neither of these documents, or alternative references such as ORNL, developed a suitable sediment benchmark for molybdenum; therefore, no benchmark on molybdenum could be developed.

Terrestrial Plants: As presented in Efroymson et al. (1997a), phytotoxicity benchmarks were selected by rank ordering the LOEC values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the benchmark. The proposed benchmark for phytotoxic effects of silver in soils is based on a LOEC of 2 mg/kg, which resulted in unspecified toxic effects on plants (Efroymson et al., 1997a). Since the CSCL was based on a single study reporting unspecified effects and did not indicate the form of molybdenum applied to test soils or the terrestrial plant species exposed, this benchmark study was not appropriate for

CSCL development. No further studies were identified, so no CSCLs could be developed for the terrestrial plant community.

Soil Community: Because no adequate data to develop community-based CSCLs were identified, criteria for soil from microbial effects presented in Efroymson et al. (1997b) of 200 mg molybdenum/kg soil was proposed; it is based on 1 reported effects on microbial activities from molybdenum exposure. The toxicity endpoints measured in microorganisms included effects such as enzyme activities, nitrogen transformation, and mineralization. These functions have been recognized to play important roles in nutrient cycling, which provides nutrients in available forms to plants. Even though microbial processes are important in soil, using this CSCL may have limited utility. Basing a CSCL on only one species or taxa does not consider the complex processes and interactions characteristic of functional soil communities. Community-based CSCLs should be used as they become available. Confidence in this CSCL is low.

Table 1. Molybdenum CSCLs in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Freshwater Community Total	3.7E-01	mg/L water	Direct contact	Aquatic biota	Suter and Tsao, 1996
Terrestrial					
Mammals	7.1E+01	mg/kg soil	Food web	Raccoon	Fungwe et al., 1990
Birds	8.8E+01	mg/kg soil	Food web	American woodcock	Sample et al., 1996
Mammals	3.6E+00	mg/kg plant tissue	Food web	Meadow vole	Fungwe et al., 1990
Birds	8.7E+01	mg/kg plant tissue	Food web	Northern bobwhite	Sample et al., 1996
Soil Community	2.0E+02	mg/kg soil	Direct contact	Soil invertebrates	Efroymson et al., 1997b

Insufficient data for aquatic birds, aquatic mammals, terrestrial plants, and benthic community

Ecotoxicological Profile for Ecological Receptors
Nickel

This ecotoxicological profile on nickel contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (5) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of nickel so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

- Nickel is present in the environment in one oxidation state (+2).
- Adsorption reactions limit nickel mobility in the environment.

Nickel and its compounds are naturally present in the earth's crust. Nickel is released to the environment by natural geochemical processes such as the weathering of parent bedrock materials and volcanic exhalations. Nickel is also released through anthropogenic activities such as the burning of residual and fuel oils, metals smelting and refining, municipal incineration, and coal combustion. Different species released during anthropogenic activities include nickel oxides, nickel sulfate, metallic nickel, and in more specialized industries, nickel silicate, nickel subsulfide, and nickel chloride.

II. Geochemistry of Nickel in Various Ecological Media

Nickel in Soils

- Nickel mobility is limited in soils due to adsorption reactions.
- Amorphous iron and manganese oxides, organic matter, and clay minerals are important adsorbents.
- Soil pH is the most important factor controlling nickel adsorption. Adsorption decreases as a function of decreasing pH.
- Two factors that may decrease adsorption are the presence of competing ions (e.g., Ca^{2+}) and/or the presence of constituents that may form soluble complexes with nickel in soil pore water.

Although nickel is a natural constituent of soils, its occurrence in soils may be attributed to input from anthropogenic sources as well as from natural weathering processes. Actual concentrations vary widely depending upon local geology and anthropogenic input. Typical concentrations of nickel in soil range from 4 to 80 parts per million (ppm).

Nickel is strongly adsorbed to soil substrates. Amorphous iron and manganese oxides, and to a lesser extent clay minerals, are the most important adsorbents in soil (EPRI, 1984). The degree to which nickel is adsorbed is dependent upon a number of factors, including soil pH, soil type and texture, organic matter content, concentration of competing ions, and concentration of complexing agents. In a study of 12 soils collected from agricultural areas and potential chemical waste disposal sites in the state of New Mexico, it was concluded that most soils have an extremely high affinity for nickel and that once sorbed, nickel is difficult to desorb, thus limiting nickel's availability and mobility in the environment.

The capacity for soils to adsorb and thus limit nickel mobility in soils was further evaluated in a study of ten mineral and three organic soils collected from southeastern United States. Samples included both surface and subsurface soils. The amount of adsorbed nickel ranged from 13 to 95 percent. The 13 percent was correlated with subsoils, whereas the 95 percent was correlated with soils having high organic matter concentrations. Hence, soils high in organic matter content were characterized in this study as having a higher sorption capacity then did mineral soils. Five to 87 percent of the nickel was non-exchangeable when extracted with potassium chloride, indicating that the nickel was strongly sorbed to the substrate.

Although nickel adsorption in soils is controlled by numerous factors, one of the most important is pH. As soil pH decreases so does nickel adsorption. This decrease may be reflected in increased concentrations of nickel in soil pore water. In acid soils, the predominant species in soil pore water include Ni^{2+}, $NiSO_4$, and $NiHPO_4$.

Competing cations and complexing ligands may significantly influence nickel adsorption by soils. Increasing ionic strength with NaCl, $NaClO_4$, $NaNO_3$, $CaCl_2$, $Ca(ClO_4)_2$, or $Ca(NO_3)_2$ reduces nickel adsorption by clays and soils. Cationic competition for adsorption sites and decreasing solution activity of Ni^{2+} are likely explanations for this phenomenon (EPRI, 1984). The presence of cations such as Ca^{2+} and Mg^{2+} have been reported to reduce nickel adsorption through competition for limited binding sites. High concentrations of chloride also decrease adsorption, but not as much as the presence of calcium ions, indicating the importance of competition in assessing the fate of nickel. The presence of potential complexing agents such as sulfate (SO_4^{2-}), dissolved organic matter, and EDTA may reduce adsorption as a result of complexation.

Nickel in Surface Water

Concentrations of nickel in surface water are low. Median nickel concentrations in rivers and lakes range from approximately 0.5 to 6 Fg/L.

The predominant form of nickel in natural waters is the hexahydrate ion ($Ni(H_2O)_6^{2+}$). At pH values less than 9, nickel can form complexes with naturally-occurring anions, such as hydroxide (OH^-), sulfate (SO_4^{2-}), bicarbonate (HCO_2^-), carbonate (CO_3^{2-}), phosphate (PO_4^{3-}), and chloride (Cl^-); however, these species are minor when compared with hydrated Ni^{2+}. As the pH increases to values equal to or greater than 9.5, $Ni(OH)_2$ becomes the dominant species.

- Nickel concentrations in surface waters are low due to adsorption, precipitation, and co-precipitation reactions that limit the concentration of dissolved-phase nickel.
- At pH values less than 9, the predominant form of nickel in natural waters is the hexahydrate ion ($Ni(H_2O)_6^{2+}$).
- In anaerobic systems, nickel sulfide (NiS) may form.

In anaerobic systems, nickel sulfide (NiS) forms if sulfur is present in the system. Nickel sulfide is characterized by low solubility, thus limiting the availability of dissolved-phase nickel in surface water.

Another means of controlling dissolved phase nickel concentrations is through precipitation. In aerobic waters, nickel ferrite ($NiFe_2O_4$) may precipitate out. Nickel may also be co-precipitated with hydrous iron and manganese oxides. Precipitates and co-precipitates will settle and accumulate in the underlying sediment.

Nickel in Sediments

Nickel present in surface water may accumulate in the underlying sediment. Nickel in sediment may be reversibly or irreversibly bound to the substrate.

- Nickel present in surface waters is likely to accumulate in the underlying sediment.
- Nickel in sediments may be re-mobilized into the water column as a result of microbial action.

Although nickel is removed from surface water bodies by precipitation and co-precipitation reactions, it is important to note that it can be re-mobilized back into the water column. Nickel can be re-mobilized by microbial action under anaerobic conditions. Re-mobilization results from enzymatic reductive dissolution of iron with subsequent release of co-precipitated metals. A lowering of the pH as a result of enzymatic reactions may indirectly enhance the dissolution of nickel. Experiments using mixed precipitates with goethite indicated that a *Clostridium* species released 55 percent of the co-precipitated nickel in 40 hours. Similarly, precipitated nickel sulfides in sediment can be mobilized through sulfur oxidation by *Thiobacilli*. In this case, the oxidized sulfur may produce H_2SO_4 and decrease the pH.

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystems

Adverse effects, such as mortality and impaired reproductive function, have been observed in aquatic biota resulting from exposure to nickel. The effects of nickel toxicity often manifest at cell membranes and may include hyperglycemia, lymphoma, and erythrocytosis (chemical form unknown) (U.S. EPA, 1986d). After three weeks of exposure to 30 µg nickel/L, a decrease in reproductive efficiency was noted in *Daphnia magna* with a 50% impairment resulting at 95 µg/L (Ni^{2+}) (Biesinger and Christensen, 1972). Decreased life spans, productivity, and body size of *Daphnia magna* have also been observed as a result of waterborne exposures as low as 5.0 µg/L (Ni^{2+}) (Lazareva, 1986). In fish, early life stages show the greatest susceptibility to nickel toxicity. During acute exposures, the growth of newly fertilized eggs of *Salmo gairdneri* (rainbow trout) was impacted at 35 µg/L of nickel. Survival and hatching dropped to zero at levels at or above 700 µg/L (Nebeker et al., 1985). These studies suggest that daphnids and fish demonstrate similar sensitivities upon chronic exposure to nickel.

Aquatic plants may also be subject to nickel toxicity, although severity is expected to vary considerably with pH and water hardness. Generally, nickel concentrations that are sufficient to induce chronic effects in freshwater animals also have deleterious effects in freshwater algal populations (chemical form unknown) (U.S. EPA, 1986d). No chronic studies were identified to characterize the long term effects of low level exposure of nickel to amphibian species (Power et

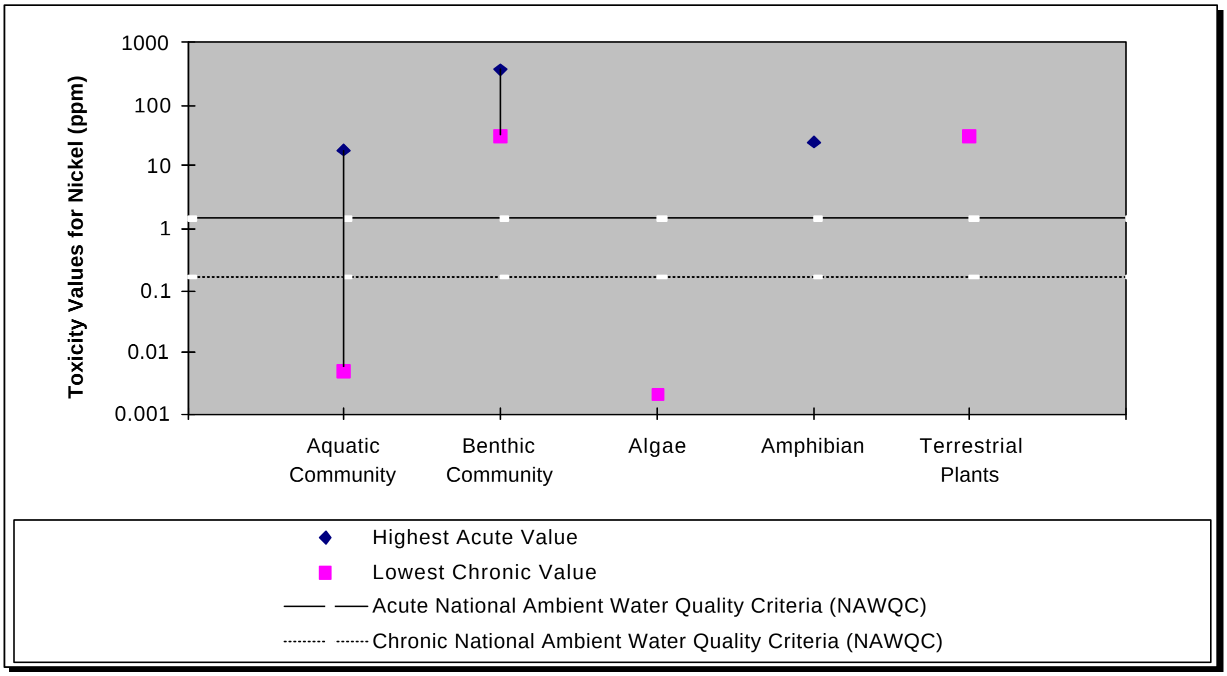

Figure 11: Nickel: Effects Ranges for Ecological Receptors

al., 1989; U.S. EPA, 1996).

Terrestrial Ecosystems

Nickel has been associated with embryotoxicity and fetal toxicity and may cross maternal-fetal barriers (Storeng and Jonson, 1981). The intraperineal injection of nickel resulted in both early and late fetal resorptions and stillborn/abnormal fetuses in exposed pregnant rats (Storeng and Jonson, 1981). Developmental toxicity as a result of oral exposure to nickel has also been noted. Dietary nickel exposures of greater than 1000 ppm nickel sulfate hexahydrate ($NiSO_4$ $6H_20$) have been demonstrated to depress growth rates in rats over a two year exposure period (Ambrose et al., 1976).

IV. Bioaccumulation Potential

Freshwater Ecosystems

Bioconcentration factors of 30 to 300 were reported for the alga *Scenedesmus obliquus* and 2 to 12 (Ni per biomass volume vs. total Ni per volume of solution) for *Daphnia magna.* These values suggest that food chain biomagnification does not occur. Increases in nickel levels in various organs (e.g., gill, kidney, liver, brain, and muscle) of the freshwater fish *Cyprinus carpio* have been reported, although data on whole body accumulations were not reported. Further, nickel accumulation in freshwater mussels have also been noted as a result of exposure to aqueous nickel solutions (Sreedevi et al., 1992). Acute effects (LC_{50}s) to amphibian embryos resulting from exposure to nickel are indicated in the range of 0.05 to 53 mg nickel/L.

For fish, Stephan (1993) reported a muscle-only bioconcentration factor of 0.80 L water/kg tissue for rainbow trout, suggesting that nickel does not bioconcentrate in fish (chemical form unspecified). However, lacking data on whole-body bioconcentration, this value should be interpreted with caution. Adequate data for assessing bioconcentration potential in other aquatic organisms were not identified.

Terrestrial Ecosystems
Bioaccumulation in terrestrial invertebrates, plants, and small mammals is currently being investigated at Oak Ridge National Labs. Bioaccumulation and bioconcentration factors (BAFs and BCFs) for terrestrial plants, invertebrates, and small mammals have been proposed from review of primary literature sources. The 90^{th} percentile of the bioaccumulation data for these receptors derived from both laboratory and field studies were used to determine terrestrial food chain exposures. For earthworms, a BAF of 4.7 was proposed for nickel based on 31 data points. For terrestrial plants, an BCF of 1.7 was proposed based on 163 data points. For small mammals, based on 43 reported values assessing the transfer of nickel from soil to small mammals, a BAF of 0.59 was proposed (Sample et al., 1997; Samples et al., 1998). These values were used to model food chain exposures to terrestrial species for this analysis, because currently, they stand as the most comprehensive collection of bioaccumulation data for terrestrial ecological receptors (Sample et al., 1997; 1998a; 1998b).

V. CSCL Development

The benchmark values presented in this section for mammals and birds were used to derive protective media-specific CSCLs as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor and the potential bioconcentration in prey, a protective concentration (i.e., CSCLs) in soil, plants or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. It is assumed that by protecting the more sensitive species, the other receptors are protected as well.

Mammals: Several studies were identified which investigated the effects of nickel exposure on mammalian species. In a 3-generation study conducted by Ambrose et al. (1976), rats were exposed to 250, 500 and 1000 ppm of dietary nickel. The average weaning body weight was adversely affected in weanlings of females on the 1000 ppm diet. This resulted in a LOAEL of 1000 ppm and a NOAEL of 500 ppm for this developmental effect. To convert the NOAEL from the Ambrose et al. (1976) study to a daily dose, the food intake rate was determined by using the food consumption equation for laboratory mammals (U.S. EPA, 1988a):

$$\textit{Food Consumption} = 0.056(W^{0.6611})$$

where W is body weight in kilograms. Using the geometric mean of the male and female control body weights (0.148 kg), and the calculated food consumption rate of 0.016 kg/day, a NOAEL of 54 mg/kg-day was estimated. The NOAEL for developmental effects from the Ambrose et al. (1976) study was chosen to derive the toxicological benchmark because (1) chronic exposures were administered via oral ingestion, (2) it focused on irregularities in the development of offspring as a critical endpoint, (3) the study contained dose response information, and (4) the study reported the lowest toxicity value for a critical endpoint.

Other benchmark studies for mammals were identified and evaluated for CSCL development. In a 3-generation study, Schroeder and Mitchener (1971b) exposed rats to nickel in drinking water at levels of 5 mg/L. Conversion of this ppm dose to a daily dose in units of mg/kg-day is in progress. In all generations, there were increases in young deaths and number of runts as well as decreases in litter size. There was also a decrease in the number of males born in the third generation. Smith et al. (1993) exposed rats to nickel in doses of 10, 50, and 250 ppm in drinking water, corresponding to average daily doses of 1.3, 6.8, and 31.6 mg/kg-day (reported in the study), for an 11-week pre-mating period. In the first generation, the proportion of dead pups per litter increased for those groups given 31.6 mg/kg-day. However, the same elevation in dead pups per litter was also seen in the second generation for those groups given 1.3 mg/kg-day and 6.8 mg/kg-day, resulting in a LOAEL of 1.3 mg/kg-day. The study by Schroeder et al. (1971b) was not selected for the derivation of a benchmark due to the administration of only one test dose, resulting in a lack of appropriate dose-response information. The Smith et al. (1990) study was not chosen due to confounding dose-response information presented in the study.

Birds: Study done by Cain and Pafford, 1981 (as cited in Sample et al., 1996) were used to derive CSCLs for birds. They examined nickel's effects on the reproduction of mallard duckling by feeding them at 176, 774, 1069 ppm. Mallards treated with 1069 ppm exhibited developmental effects. Based on these results, a NOAEL of 774 ppm and a LOAEL of 1069 ppm can be inferred for developmental effects. As reported by Sample et al. (1996), the NOAEL for mallards is 77.4 mg/kg-day and the LOAEL is 107 mg/kg-day. Additional avian toxicity data were not identified for birds representing the terrestrial ecosystem. Therefore, the study used for freshwater ecosystem was also used to calculate terrestrial avian CSCLs values.

Freshwater Community: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria (NAWQC) published by the EPA Office of Water. The FCV of 5.2E-02 mg/L for nickel developed under the GLWQI was selected as the appropriate criteria to use in this analysis. The GLWQI value was considered preferable to the NAWQC because: (1) the GLWQI value is based on the same methodology used to develop NAWQC (i.e., Stephan et al., 1985); (2) the NAWQC data set was augmented with previously unavailable acute and chronic toxicity data; and (3) species taxa used to generate the GLWQI values are suitable for national application since they include species and taxa found throughout the United States. The toxicity of nickel is hardness dependent; therefore, the FCV (in µg/L) was calculated using the following equation (U.S. EPA, 1995a), assuming a water hardness of 100 mg/L as calcium carbonate ($CaCO_3$):

$$e^{0.846(\ln \text{hardness}) + 0.0584}$$

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metal concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). Consequently, the FCV for nickel was adjusted to provide dissolved concentrations as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). The nickel FCV was adjusted using a conversion factor (CF) of 0.997 for chronic effects to give a dissolved surface water CSCL of 5.2E-02 mg/L. This adjustment reflects the current Agency position on criteria development and regulatory application of metals; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). For example, the relationship between water characteristics (e.g., dissolved organic matter), copper bioavailability, and toxicity has been investigated in some detail (e.g., Allen and Hansen, 1996). For completeness, the total and dissolved surface water CSCLs are presented in Table 1 even though the values are identical.

Amphibians: No suitable subchronic or chronic studies were identified which studied the effects of nickel toxicity on reproductive or developmental endpoints in amphibian species; however, several acute studies were identified characterizing nickel toxicity. Review of data collected from nine experiments indicate that the acute toxicity of nickel ranges from 0.05 to 53 mg/L, with a geometric mean of 2.2 mg nickel/L. Acute studies were conducted on various amphibian species (i.e., five amphibian species represented) during embryo lifestages. The observation that the lowest acute amphibian value (i.e., 0.05 mg nickel/L) is over one order of magnitude below the FAV, of 1.4 mg nickel/L and approximates the FCV (0.052 mg nickel/L) determined for the freshwater community indicates that some amphibian species may be equally or more sensitive than other freshwater receptors (i.e., acute effects may occur at levels deemed to be protective of the aquatic community, SCV). Given the lack of chronic amphibian data, a CSCL of 2.2 mg nickel/L was derived based on acute toxicity. Since the CSCL is based on acute data (i.e., lethality), the severity of the potential adverse effects that this CSCL indicates should be noted. Investigations are ongoing to review the possibility of incorporating amphibian data into the NAWQC. Since amphibian species are more likely to breed in standing waters such as wetlands or ponds, the appropriateness of combining protective levels of amphibian receptors and the freshwater community is unclear at this time (Power et al., 1989; U.S. EPA, 1996).

Algae and Aquatic plants: The benchmarks for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or (2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). For nickel the benchmark value presented in Suter and Tsao (1996) of 5.0E-03 mg/L was based on the incipient inhibition of *Microcystis aeruginosa*. Low confidence is placed in this CSCL since it is only based on one study.

Benthic Community- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, CSCLs are developed estimating the 10th percentile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). These values are not NOAA standards; rather, they are used to rank sites based on the potential for adverse ecological effects. A second criteria document evaluated for sediment criteria development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the criteria was changed. FDEP calculated the criteria (i.e., threshold effects level, TEL) from the geometric mean of the 50^{th} percentile of no effects data and the 15^{th} percentile of the low effects data. The NOAA data, used in both documents, is based on total metal concentrations in sediments, and the toxicity endpoints were measured on species of amphipods, arthropods, and bivalves in addition to a variety of community-based endpoints (e.g., abundance, mortality, species composition, species richness). The FDEP criterion was chosen above the NOAA criterion for the following reasons; (1) the same database was used for both the NOAA criteria and the FDEP criteria development only different derivation methods were used; (2) in most cases, the FDEP criterion was more conservative than the NOAA criteria because a larger portion of the low effects data was used in benchmark development; (3) the marine TEL developed by the FDEP were found to be analogous to TELs observed in freshwater organisms (Smith et al., 1995).

The CSCL for nickel was derived from 355 toxicity data points for low and no effects levels. For the screening level analysis of nickel, the TEL of 1.6E+01 mg nickel/kg sediment was selected as an appropriate sediment CSCL. Based on the quality and quantity of nickel sediment data, the degree of confidence in the TEL value for nickel was considered high (MacDonald, 1994).

Terrestrial Plants: As presented in Efroymson et al. (1997a), phytotoxicity benchmarks were selected by rank ordering the lowest observable effects concentration (LOEC) values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the benchmark. Such LOECs applied to reductions in plant growth, yield, or seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. The selected benchmark for phytotoxic effects of nickel in soils is 30 mg/kg (Efroymson et al., 1997a). The derivation of the CSCL is based on 14 phytotoxicity data points on various agricultural (e.g., barley, ryegrass) species measuring growth endpoints such as height and weight of shoots and roots. Considering this CSCL was based on multiple studies over a range of species, confidence in this benchmark is high.

Soil Community: Because no adequate data to develop community-based CSCLs were identified, CSCL for soil from microbial effects presented in Efroymson et al. (1997b) of 90 mg nickel/kg soil was proposed; it is based on 56 reported effects on microbial activities from nickel exposure. The toxicity endpoints measured in microorganisms included effects such as enzyme activities, nitrogen transformation, and mineralization. These functions have been recognized to play important roles in nutrient cycling, which provides nutrients in available forms to plants. Even though microbial processes are important in soil, using this CSCL may have limited utility. Basing a CSCL on only one species or taxa does not consider the complex processes and interactions characteristic of functional soil communities. Community-based CSCLs should be used as they become available. Confidence in this CSCL is low.

Table 1. Nickel CSCLs in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Mammals	9.5E+01	mg/L water	Food web	River Otter	Ambrose et al., 1976
Birds	2.3E+02	mg/L water	Food web	Kingfisher	Sample et al., 1996
Algae and Aquatic Plants	5.0E-03	mg/L water	Direct contact	*Microcystis aeruginosa*	Suter and Tsao, 1996
Freshwater Community					
Total	5.2E-02	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1995b
Dissolved	5.2E-02	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1995b; 60FR22229
Benthic Community	1.6E+01	mg/kg sediment	Direct contact	Benthos	MacDonald, 1994
Amphibians (acute effects)	2.2E+00	mg/L water	Direct contact	Various amphibian species	Power et al., 1989; U.S. EPA, 1996
Terrestrial					
Mammals	2.8E+02	mg/kg soil	Food web	Meadow vole	Ambrose et al., 1976
Birds	6.7E+02	mg/kg soil	Food web	American woodcock	Sample et al., 1996
Mammals	2.4E+02	mg/kg plant tissue	Food web	Meadow vole	Ambrose et al., 1976
Birds	1.7E+03	mg/kg plant tissue	Food web	Northern bobwhite	Sample et al., 1996
Plant Community	3.0E+01	mg/kg soil	Direct contact	Plants (unspecified species)	Efroymson et al., 1997a
Soil Community	9.0E+01	mg/kg soil	Direct contact	Soil invertebrates	Efroymson et al., 1997b

Ecotoxicological Profile for Ecological Receptors
Selenium

This ecotoxicological profile on selenium contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (5) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of selenium so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

Selenium is an essential nutrient for many ecological receptors, but it has also been implicated in deleterious effects a high concentrations. The range between beneficial and harmful levels is quite narrow such that concentrations that are required for some species may inhibit physiological processes in other species. For example, the recommended concentration of selenium for freshwater aquatic organisms is approximately 35 ppb; however, concentrations from 60 to 600 ppb result in mortality to sensitive aquatic organisms. Therefore, an increase in 25 ppb of selenium can result in adverse effects to some receptors. The biological response of organisms will vary depending on the species, age, tolerance, and the chemical form of selenium.

The environmental behavior of selenium is complex and not well characterized; however, it is an issue of current research. The bioaccumulation and biomagnification of selenium in aquatic and terrestrial receptors has been observed. Adverse impacts to receptors at high trophic levels (i.e., mammals and birds) has been well documented in case studies conducted at the Kesterson Reservoir, San Joaquin River, and Belews Lake, NC.

II. Geochemistry of Selenium in Various Ecological Media

General

Knowledge of selenium speciation and partitioning within various environmental compartments is important in the evaluation of potential risks arising from toxicity. Selenium can exist in a variety of oxidation states (-2, 0, +4, +6), in both organic and inorganic compounds. Since the different oxidation states of selenium are characterized by unique solubilities and affinities for solid phases, changes from one oxidation state to another affects the potential mobility in the environment. Hence, the wide variations in selenium solubility and sorption characteristics among its different forms require that its speciation be understood in order to predict transport between environmental compartments.

- Selenium can exist in four oxidation states (-2, 0, +4, +6). In aqueous environments, selenium is limited to the -2, +4, and +6 oxidation states.
- Selenium is biologically active and can form organic as well as inorganic compounds.
- The specific oxidation state and chemical form largely determine selenium's behavior in the environment.

The geochemical behavior of selenium in the environment is strongly dependent upon its oxidation state and specific chemical species. Selenium occurs in four oxidation states: -2, 0, +4, and +6. Selenium^{6+} and Se^{4+} occur as the oxyanions selenate (SeO_4^{2-}) and selenite (SeO_3^{2-} and $HSeO_3^-$), respectively. Elemental Se (Se^0) occurs in colloidal form; whereas, selenide (Se^{2-}) occurs as a variety of organic and inorganic selenides, including volatile methylated forms.

The specific chemical species will depend to a large degree on its oxidation state, which in turn, is influenced by pH and Eh. Thermodynamically, selenate (SeO_4^{2-}) should be the stable selenium species in oxic and alkaline environments; however, data from natural systems indicate that speciation is complex and cannot be predicted based on thermodynamics alone. Specifically, thermodynamics do not take into account biological production of apparently unstable species, nor the apparent stabilities of thermodynamically-predicted unstable species due to kinetic hindrances to equilibrium (Doyle et al., 1995).

Selenium in Soils

The amount of selenium in soils is determined primarily by natural geochemical processes such as the weathering of parent bedrock materials or volcanic exhalations; however, anthropogenic sources may also contribute selenium to the soil system. Anthropogenic sources include coal/oil combustion facilities, selenium refining factories, base metal smelting and refining factories, mining and milling operations, as well as fertilizer applications and incineration of tires, paper, and municipal waste (ATSDR, 1996).

Selenium speciation in soils is a function of soil pH and Eh. Selenium may occur in a number of different forms, including elemental selenium, selenides, selenites, selenates, and organic selenium. Elemental selenium (Se^0) is formed by bacteria, fungi, and algae, which are capable of reducing selenites and selenates. Elemental selenium is moderately stable in soils and is essentially insoluble, thus representing an inert sink under anoxic conditions.

- Selenium speciation is a function of soil pH and Eh.
- Depending upon pH and Eh, selenium may occur as elemental selenium, selenides, selenites, selenate, and organic selenium.
- Elemental selenium occurs under anerobic conditions. It is relatively stable and insoluble.
- Selenides predominate in acidic soils and soils with high organic content. They are also relatively stable and insoluble.
- Selenites are thermodynamically stable under reducing conditions, but may exist under oxidizing conditions as well. They are stable in alkaline to mildly acidic environments. Although they are soluble, they sorb onto iron oxides and organic matter, thereby limiting their mobility in the environment.
- Selenate is the predominant species at pH values greater then 6.5 and oxidizing conditions. It is characterized as being soluble and having a low sorption potential. It is readily available for uptake by plants.
- A variety of organic complexes may exist. These complexes are most prevalent in high organic soils.

Heavy metal selenides and selenium sulfides are also largely insoluble. They predominate in acidic soils and soils characterized by high organic matter content. Heavy metal selenides and selenium sulfides are generally considered immobile in soil. This is due to the low solubility that characterizes metal selenides such as copper and cadmium.

Elemental selenium can be oxidized to form selenites and selenates. The selenites (SeO_3^{2-}) are stable, under moderately reducing conditions, in alkaline to mildly acidic environments (Shamberger, 1983; Tokunaga et al., 1997). Although the selenites are soluble, they can strongly sorb onto surfaces of common soil minerals (iron oxides) and organic matter (Tokunaga et al., 1997). Selenites may also be removed from pore waters through the formation of an insoluble precipitate (basic ferric selenite [$Fe_2(OH)_4SeO_3$]), which can be formed in acidic soils (4.5 < pH < 6.5). Geering et al. (1968) indicated that the selenite concentration in solution in soils is governed primarily by this ferric oxide-selenite complex.

At pH values greater then 6.5, selenium may be oxidized to the more soluble selenate ions (SeO_4^{2-}). Because of its relatively high solubility and low tendency to sorb onto soil particles, selenates are readily available for transport and uptake by plants. Soluble selenate (principally sodium selenate) appear to be responsible for most of the naturally occurring accumulation of high selenium in plants.

Selenium in organic complexes occurs in varying quantities in soils. Organic species of selenium can be increased by the accumulation of decaying plant residues. Organic selenium is also subject to microbiological breakdown, resulting in alkylselenium compounds, mainly dimethylselenide. In humic temperate regions with the relatively greater accumulation of soil organic matter, organic-selenium forms assume more importance. Organic soils retain selenium ore strongly than mineral soils. Studies have shown that the addition of organic matter greatly diminished the evolution of volatile selenium compounds as well as the movement and leaching of selenium through soil columns (Ihnat, 1989).

Based on the behavior of selenium in soils, it is expected that selenium would be concentrated in soil horizons characterized by either high iron contents or high organic matter contents. In New Zealand soil profiles, Wells (1967) found that B2 horizons, with their accumulation of iron and clay-sized colloids, were characterized by the greatest selenium concentrations. In another study conducted in the United States, selenium concentrations were found to range from 0.01 to 2.5 mg/kg in 11 soil profiles collected in the United States (Ihnat, 1989). The most ferruginous horizons of the soils were found to be the most seleniferous. In acid ferruginous soils, selenium was bound as a basic ferric selenite or strongly absorbed on ferric oxide. Lateritic soils of the continental United States that have been analyzed also contain 0.5 to 2.4 mg/kg of selenium in the iron-rich horizons (Shamberger, 1983).

An accumulation of selenium in podzolic B horizons and organic surface horizons was found in 54 Canadian profiles by Levesque (1974). In Finnish soils, Koljonen (1975) found that selenium was enriched in the O-A1 horizons rich in organic matter and in the iron-rich B horizons. Multiple regression analysis revealed that the predominant factors involved in selenium distribution were the content of the parent material and the organic carbon content of the upper soil horizons (Ihnat, 1989).

Selenium in Surface Water

The data for selenium in surface water can be divided into two operationally-defined fractions: dissolved selenium (passes through filters with 0.45 Fm openings) and particulate selenium (trapped by filters having $ 0.45 Fm openings, typically suspended sediment and other suspended solids). Particulate selenium exists in the same oxidation states as dissolved selenium.

Dissolved selenium exists in three oxidation states, including selenide (Se^{2-}), selenite (Se^{4+}), and selenate (Se^{6+}). Although not truly dissolved, colloidal selenium passes through filters having 0.45 Fm openings, and as a consequence, is grouped with the dissolved selenium phase. Colloids may consist of elemental selenium (Se^0).

> It is important to remember that thermodynamic calculations describing selenium geochemistry can be misleading. In fact, thermodynamically-unstable species have been measured at significant concentrations in natural waters. The presence of these species is attributed to biological mediation and/or kinetic hindrances to equilibrium.
>
> - Selenate is the thermodynamically stable species under oxic and alkaline conditions.
> - Selenite may also exist and should be assumed to be present.
> - Elemental selenium and selenides dominant under anoxic conditions.
> - Organic selenides may be present under both oxic and anoxic conditions.

Although selenate is the thermodynamically-stable species under oxic and alkaline water conditions, both selenite and selenate are common in surface waters (ATSDR, 1996). Selenite exists as $HSeO_3^-$ at pH 6. As the pH increases, the concentration of $HSeO_3^-$ becomes less prevalent and SeO_3^{2-} increases in importance. At a pH of 9, SeO_3^{2-} exceeds $HSeO_3^-$ by a ratio of about 2:1. Dissolved selenate is present as SeO_4^{2-} in oxic waters having a pH range of 6 to 9.

The thermodynamic models predict that elemental selenium and selenide should dominate under anoxic conditions. Selenide may be present as H_2Se and HSe^- in anoxic waters. It may also be present as organic selenides (primarily selenoamino acids bound in soluble peptides) in oxic and anoxic waters.

Although selenate is expected to be the dominant form of selenium in surface water, significant variability in speciation exists. In the Susquehanna River, which empties into the Chesapeake Bay, selenate is the predominant form of dissolved selenium (69% of the total). In contrast, samples from the St. Lawrence River in Canada show selenite to be the selenium species of highest concentration (67 - 76% of the total). Furthermore, recent data for several rivers in North America show that selenite and organic selenide (Se^{2-} and Se^0) are the dominant species. Specifically, it was found that 77% of the inorganic selenium can be classified as colloidal, whereas 70% or the organic selenium is colloidal, in river water collected from the James River in Virginia.

Because selenium is of special concern in the western United States due to widespread areas of selenium-rich source rocks, arid climate, and the potential for evapoconcentration, factors controlling transport and behavior in arid fluvial systems were investigated by Doyle et al. (1995). The three river systems included the Truckee, Walker, and Carson River watersheds, which comprise an area of over 200,000 km^2 in eastern California and western Nevada.

Selenium concentrations of < 1 to ~ 3 nM were measured in the three watershed systems. The source of the selenium appears to be atmospheric input and not geologic weathering. Despite the ability of selenium to evapoconcentrate, evidence indicated that it did not behave conservatively and was in fact depleted relative to other conservative species. Possible removal mechanisms include:

- selenate reduction in anoxic bottom sediments and/or waters of the terminal lakes,
- volatilization to the atmosphere via planktonic biomethylation,

- incorporation of selenium-rich organic matter into sediments and subsequent burial, and/or
- adsorption of thermodynamically-unstable selenium onto iron oxides.

Selenium in Sediments

- Most of the selenium in surface water-sediment systems is found in the sedimentary phase.
- Total dissolved selenium decreases more rapidly when organic matter is present in the system.
- Accumulations of selenium within sediments are largely confined to the near surface.
- Reducing conditions in the sediment promote the reduction of selenite and selenate to elemental selenium.

Transport across boundaries between surface waters and the underlying sediments is important in understanding the cycling of selenium. On a total mass basis, most of the selenium in surface water-sediment systems can be found in the sediments (Cutter, 1989). Selenium may be associated with the organic material, iron and manganese oxides, carbonates, or other mineral phases, that constitute a sediment particle. This association is attributed to abiotic and biotic scavenging of dissolved ions from the water column and burial in the underlying sediments. Abiotic scavenging includes selenium adsorption and/or co-precipitation (primarily selenite and selenate). Selenide can be covalently bound in the organic portion of a sediment (the association of selenide with organic materials in sediment reflects the reducing conditions typical of organic matter). In addition, selenium may be found in anoxic sediments as insoluble metal selenide precipitates, as insoluble elemental selenium, or as ferroselite ($FeSe_2$) and selenium-containing pyrite.

In experiments designed to determine trends in inorganic selenium concentrations in water columns associated with sediment and sediment augmented with organic matter, it was found that there was a net decrease in total dissolved selenium in the water columns of both sediment systems (Tokunaga et al., 1997). More rapid decreases were observed in systems having organic matter added to the sediment. By the end of the experiment, 25% of the original selenium in the surface waters was transported into the unamended sediments. For systems, amended with organic matter, 95% of the selenium originally in the ponded water was transported into the sediments. Accumulations of selenium within the sediments were largely confined to the near-surface regions (< 25 mm depth) in both sets of experiments. Reducing conditions in the sediment promoted the reduction of selenate to selenite to elemental selenium, allowing a net accumulation of insoluble selenium species. The highest accumulations of selenium in the sediment occur within the top 1 mm of the columns, indicating a rapid reduction to elemental selenium.

Selenium concentrations in sediment are generally in the range of 1.5 to 4 mg/kg (Cutter, 1989). However, sedimentary accumulation of selenium will depend on a number of factors, including the total dissolved concentration of selenium in the system, sedimentation rate, biological productivity, and sediment type. Sediments in reservoirs that receive fossil fuel combustion products (e.g., fly ash) are characterized by elevated selenium concentrations. Cutter (1986) analyzed the concentration and phase distribution of selenium in sediments from three power plants-receiving waters (coal fly ash was the major source of selenium in the receiving waters). Within the sediments, selenium ranged in concentration from 6.5 to 29 mg/kg. Cutter (1986) indicated that more than 90 percent of the selenium was present in an “organic phase;” however, this organic phase is considered an operational definition and may include both elemental selenium and/or a selenium sulfide phases.

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystems

Sensitive aquatic organisms exhibit increased mortality at water concentrations of selenium between 60 and 600 ppb selenium (chemical form unspecified). Selenium's toxic effects in fish may vary with life stage, but include behavioral changes, altered blood chemistry, and decreased reproductive success (Eisler, 1985b). Selenite is significantly more toxic than selenate, and younger life stages are more sensitive than older (Hamilton and Buhl, 1990). For selenite, LC_{50} values of 13.8 mg/L for chinook salmon and 7.8 mg/L for coho salmon were reported; for selenate, the corresponding values were 115 mg/L and 33 mg/L. Aquatic invertebrates demonstrate higher sensitivity to acute exposures than fish with LC_{50} values ranging from 0.07 to 0.8 mg/L (Eisler, 1985b). Amphibians exposed to water concentrations of selenium as sodium selenite have also shown adverse effects. Exposure to 2.0 mg/L and above during the egg stage of *Xenopus laevis* caused developmental malformations (chemical form unknown). Exposure during the tadpole stage resulted in altered behavior and physiological function (Power et al., 1989). Lethality to amphibians was observed in surface water concentrations ranging from 7 to 11 mg selenium/L (as sodium selenate). In algal communities, concentrations between 47 to 53 ppb have resulted in inhibited growth and shifts in representative species. No ecotoxicity data on potential effects to the sediment community could be identified (Power et al., 1989; U.S. EPA, 1996).

Terrestrial Ecosystems

Both acute and chronic effects have been indicated in terrestrial receptors. Acute selenosis in livestock may result from ingestion of highly contaminated plants and may produce death. Plant materials containing 400 to 800 ppm selenium have been found to produce acutely toxic effects. The minimum orally-administered lethal dose, in mg Se/kg-body weight, range from 3.3 for horses, to 11 for cattle, to 15 for swine (Eisler, 1985b). Chronic selenosis in mammals may result from dietary exposures ranging from 1 ppm (rat) to 44 ppm (horse) and drinking water exposures of 0.5 to 2.0 ppm (Harr and Muth, 1972). Selenosis has also been associated with reproductive anomalies, including congenital malformations and growth retardation (Eisler, 1985b). Rats dosed with selenium as selenate at 0.34 mg/kg-day for two generations demonstrated decreased reproductive success (Rosenfeld and Beath, 1954). In

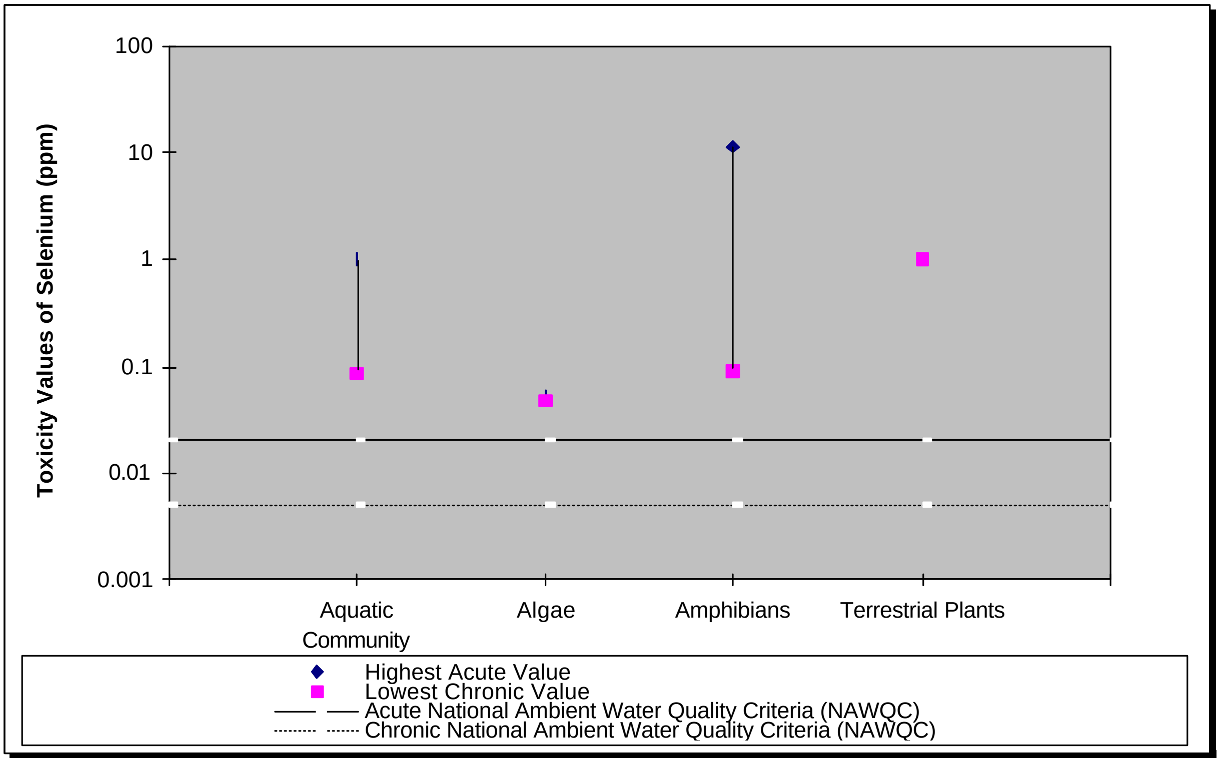

Figure 12: Selenium: Effects Ranges for Ecological Parameters

general, studies on rats, mice, swine, and cattle, have found that the young born to females with selenosis were emaciated, were unable to nurse, were part of small litters, and exhibited high mortality rates (Eisler, 1985b). Although some studies have reported carcinogenicity, selenium's carcinogenic potential remains unclear (IRIS;U.S. EPA, 1992-1996).

Limited literature sources were identified to evaluate the direct impacts to terrestrial plant and soil communities; however, overall impacts appear less severe in these receptors. Their role as bioaccumulators and vectors of exposure to higher trophic levels may play a more significant part in the observed ecological impacts of selenium. In plants, the lowest observed effects concentrations have been reported in the range of 1 to 4 ppm; whereas, acutely toxic concentrations of 25 to 50 ppm have been observed (Efroymson et al., 1997a; Eisler, 1985b). One study identifying reproductive effects of selenium to cocoon production in earthworms reported no effects at 77 ppm.

IV. Bioaccumulation Potential

Freshwater Ecosystems

Selenium accumulates in the aquatic environment in many kinds of organisms, including algae, periphyton, daphnids, benthic insects, annelids, molluscs, crustaceans, and fish, as well as birds (Besser et al., 1993; Lemly, 1985; Ohlendorf et al., 1990). Ohlendorf et al. (1990) studied accumulation of selenium in aquatic birds living near contaminated water bodies. They found that selenium concentrations in liver tissues of birds from this site were much higher, often ten times or more, than those of birds living in relatively uncontaminated reference sites. Evidence suggests that accumulation of selenium occurs more readily as organoselenium compounds than as inorganic forms. Preferential uptake of selenomethionine relative to inorganic species has been reported in algae, daphnids, and fish (Lemly, 1985; Besser et al., 1993). Consumption of selenomethionine has also been shown to be more effective than sodium selenite in raising the selenium content of bird tissues and eggs (Eisler, 1985b). Low concentrations of Se-methionine could thus contribute significantly to selenium bioaccumulation and toxicity in aquatic biota, although the chemical forms and concentrations of specific organoselenium compounds are not often reported in the literature, making assessments of their toxicological importance difficult (Besser et al., 1993).

Bioaccumulation factors (BAFs) for selenium used to determine food chain exposures are based on studies from Lemly (1985). This important field study is based on selenium concentration in fish inhabiting a river basin where selenium enters the reservoir as part of coal ash disposal. Lemly (1985) suggests that selenium can not only biomagnify through the food chain, but that the large amount of selenium accumulated in higher trophic piscivorus fish can shut down their reproductive system, and in many cases, cause death. Because this is a field study where the fish receives exposure of selenium via food and water, values presented in Lemly (1985) are bioaccumulation factors (BAFs). A muscle-based BAF of 1,692 L/kg is used to represent trophic level 4 fish for estimating food chain exposures to piscivorus mammals and birds; this value is based on the geometric mean of the BAFs 1571, 2019, and 1527 L/kg from piscivorus fishes such as crappie (*Pomoxis* sp.), Largemouth bass (*Micropterus salmoides*), and white perch (*Morone americana)*, respectively. Additionally, a BAF of 485 L/kg from blueback herring(*Alosa aestivalis*) and threadfin shad (*Dorosoma petenense*) represents BAFs for trophic level 3 fish for estimating food chain exposures to piscivorous wildlife. Because no whole-body BAFs are identified, the muscle-based BAFs are used. As an aside, all BAF values are taken from Table 4 of Lemly (1985); although they are presented in units of L/g, they seem to be too high for even the most bioaccumulative constituents. A closer examination on the concentration of selenium in fishes (Figure 4 and 5) and concentration of selenium strongly suggest that the values in Table 4 are in units of L/kg rather than in L/g.

Terrestrial Ecosystems

Bioaccumulation in terrestrial invertebrates, plants, and small mammals is currently being investigated at Oak Ridge National Labs. Bioaccumulation and bioconcentration factors (BAFs and BCFs) for terrestrial plants, invertebrates, and small mammals have been proposed from review of primary literature sources. The 90th percentile of the bioaccumulation data for these receptors derived from both laboratory and field studies were used to determine terrestrial food chain exposures. For earthworms, a BAF of 1.3 was proposed for selenium based on 14 data points. For terrestrial plants, an BCF of 26 was proposed based on 237 data points. For small mammals, based on 35 reported values assessing the transfer of selenium from soil to small mammals a BAF of 1.2 was proposed (Sample et al., 1997; Samples et al., 1998). These values are in the process of being reviewed for use in modeling food chain exposures to terrestrial species, but currently, they stand as the most comprehensive collection of bioaccumulation data for terrestrial ecological receptors. Further review of methods and primary literature is currently being conducted on these high-end values (Sample et al., 1997; 1998a; 1998b).

V. CSCL Development

The benchmark values presented in this section for mammals and birds were used to derive protective media-specific CSCLs as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor and the potential bioconcentration in prey, a protective concentration (i.e., CSCLs) in soil, plants or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. It is assumed that by protecting the more sensitive species, the other receptors are protected as well.

Mammals: Rosenfeld and Beath (1954) examined the effects of selenium on the reproduction of successive generations of Wistar rats. The authors administered doses of 1.5, 2.5 and 7.5 ppm of selenium as selenate in drinking water. The 2.5 ppm dose was reported to have reduced the number of young reared by the second generation mothers by fifty percent. This reduction resulted in a LOAEL of 2.5 ppm and a NOAEL of 1.5 ppm. These effects levels correspond to daily doses of 0.34 and 0.20 mg/kg-day, based on the Wistar rat's reference body weight of 0.320 kg and water consumption rate of 0.043 L/day (U.S. EPA, 1988a).

The NOAEL of 0.20 mg/kg-day for reproductive effects from the Rosenfeld and Beath (1954) study was chosen to derive the toxicological benchmark for the following reasons: (1) doses were administered over a chronic duration and via oral ingestion, an ecologically significant exposure pathway;(2) it focused on long-term reproductive success as a critical endpoint; (3) it contained dose response information; and (4) it resulted in the lowest toxicity value for a critical endpoint.

Schroeder and Mitchener (1971b) assessed the reproductive effects of selenium in three generations of mice. A single dose of 3 ppm selenium as selenate was administered in drinking water. Mice in all three generations produced fewer offspring and a greater percentage of runts than the controls. Conversion of the 3 ppm dose to a daily dose in units of mg/kg-day required the use of an allometric equation for water consumption by laboratory mammals (U.S. EPA, 1988a):

$$\textit{Water Consumption (L/day)} = 0.10(W^{0.7377})$$

where W is body weight in kilograms. Using a reference body weight for two typical types of laboratory mice (0.035 kg) (U.S. EPA, 1988a) and a calculated water consumption rate of 0.008 L/day, a daily dose of 0.69 mg/kg-day was calculated. Nobunaga et al. (1979) exposed mice to two oral doses of selenium as selenite in drinking water for 30 days prior to mating and for the first 18 days of gestation. No significant effects on reproduction or incidences of fetotoxicity were evident at the lower dose of 11.4 nmol/ml (NOAEL), however, the higher dose of 22.8 nmol/ml (LOAEL) resulted in a significant reduction in fetal growth. These effects levels correspond to daily doses of 0.9 mg/kg-day and 1.7 mg/kg-day. To arrive at these figures, the molecular weight of sodium selenite was used to convert the nmol/ml doses to ppm doses. The ppm dose was then converted to the daily dose by using the geometric mean of mice body weights (0.028 kg) given in the study, and a water intake rate of 0.007 L/day, calculated from the allometric equation presented above (U.S. EPA, 1988a).

The Schroeder and Mitchener (1971b) study was not chosen for the derivation of the benchmark because it did not contain sufficient dose response information. The Nobunaga (1979) study was not chosen because it did not report the lowest toxicity value for a critical endpoint. The same surrogate species study (Rosenfeld and Beath, 1954) was chosen to derive the selenium benchmark for mammalian species representing the terrestrial ecosystem.

Birds: Only one study was identified that investigated the effects of selenium toxicity on avian species. Mallard duck pairs were fed diets containing selenium for 4 weeks prior to egg laying at doses of 1, 5, 10, 25 and 100 ppm selenium as sodium selenite (Heinz et al., 1987). There were no effects on the weight or survival of adults at the 1, 5, and 10 ppm dose levels. At the 25 ppm level females took longer to begin laying eggs and intervals between eggs were longer. Survival of ducklings in the 25 ppm group was lower than in the lower exposure groups. Among ducks fed 10 ppm and 25 ppm, there was a significantly greater frequency of lethally deformed embryos, as compared to the lower exposure treatment groups. This resulted in a LOAEL of 10 ppm and a NOAEL of 5 ppm. These effects levels correspond to daily doses of 1.0 and 0.5 mg/kg-day, respectively, converted by using the food intake rate of 105.5 g/day and the geometric mean (1.055 kg) of the control body weights given in the study.

The NOAEL of 0.5 mg/kg-day from the Heinz et al. (1987) study was selected to derive the avian benchmark value for the freshwater ecosystem because: (1) chronic exposures were administered via oral ingestion; (2) reproductive toxicity was one of the primary endpoints examined, and (3) the study contained sufficient dose-response information. As in the freshwater ecosystem, the study by Heinz et al. (1987) was used to calculate the benchmarks for birds in the generic terrestrial ecosystem.

Freshwater Community: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria (NAWQC) published by the EPA Office of Water. The FCVs of 5.0E-03 mg/L for total selenium, 2.8E-02 mg/L for selenium IV, and 9.5E-03 mg/L for selenium^{6+} developed under the GLWQI were selected as the appropriate criteria to use in this analysis. The GLWQI values were considered preferable to the NAWQC because: (1) the GLWQI values are based on the same methodology used to develop NAWQC (i.e., Stephan et al., 1985); (2) the NAWQC data set was augmented with previously unavailable acute and chronic toxicity data; and (3) species taxa used to generate the GLWQI values are suitable for national application since they include species and taxa found throughout the United States.

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metals concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). EPA has developed conversion factors (CFs) to estimate probable dissolved concentrations of metals in surface waters given a total metal concentration as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). A CF is not yet available for selenium. This adjustment reflects the current Agency position on criteria development and regulatory application of metals; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). The final surface water CSCL for selenium species is presented in Table 1.

Amphibians: No suitable subchronic or chronic studies were identified which studied the effects of selenium toxicity on reproductive or developmental endpoints in amphibian species Acute toxicity data on selenium was identified to range from 7 to 11 mg/L during embryo exposures of

Xenopus laevis. Low effects and no effects data were identified in one study with reported values to 1.6 and 0.8 mg selenium/L, respectively (U.S. EPA, 1996). Using this range as a guide, both of these values fall above the NAWQC; however, lacking sufficient data on various species, exposure durations, and life stages the assertion of protection under the NAWQC cannot be made. Given the limited number of studies and the lack of consistency (e.g., endpoints and test protocols) in chronic amphibian data, a CSCL of 1.6 mg selenium/L was derived based on acute toxicity. Since the CSCL is based on acute data (i.e., lethality), the severity of the potential adverse effects that this CSCL indicates should be noted. Incorporating the amphibian data into the NAWQC within the data requirement categories is currently under consideration. Since amphibian species are more likely to breed in standing waters such as wetlands or ponds, the appropriateness of combining protection of amphibian receptors with the aquatic community is unclear (Power et al. 1989; U.S. EPA, 1996).

<u>*Algae and Aquatic plants*</u>: The benchmarks for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g. duckweed) or (2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). The benchmark value for selenium reported by Suter and Mabrey (1994) was 1.0E-01 mg/L (selenate) based on the growth inhibition of the green alga *Scenedesmus obliquus* in 14-day chronic toxicity tests. The selection of a benchmark based on selenium as selenate is preferred because plants show preferential uptake of this form. Low confidence is placed in this CSCL since it is only based on one study.

<u>*Benthic Community*</u>- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, CSCLs are developed estimating the 10th per-centile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). For our purposes, the ER-L was considered an appropriate benchmark for freshwater sediment biota. A second criteria document evaluated for sediment criteria development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the criteria was changed. Neither of these documents developed a suitable sediment benchmark for selenium. A value (1.0E-01 mg selenium/kg sediment) was proposed by U.S. EPA, 1997 in the *Protocol for Screening Level Ecological Risk Assessment at Hazardous Waste Combustion Facilities*; however, since this CSCL was derived from one individual data point, we did not selected this value. Therefore, no benchmark on selenium could be developed.

<u>*Terrestrial Plants*</u>: As presented in Efroymson et al. (1997a), phytotoxicity benchmarks were selected by rank ordering the lowest observable effects concentration (LOEC) values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the benchmark. Such LOECs applied to reductions in plant growth, yield, or seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. The selected benchmark for phytotoxic effects of selenium in soils is 1.0 mg/kg (Efroymson et al., 1997a). The derivation of the CSCL is based on 13 phytotoxicity data points on

various agricultural (e.g., barley, ryegrass) species measuring growth endpoints such as height and weight of shoots and roots. Considering this CSCL was based on multiple studies over a range of species, confidence in this benchmark is high.

Soil Community: Because no adequate data to develop community-based CSCLs were identified, CSCL for soil from earthworm studies presented in Efroymson et al. (1997b) of 70 mg/kg for selenium was used; it is based on 1 study reporting effects on growth and reproduction of *Eisenia fetida*. Earthworms have been recognized to play important roles in promoting soil fertility, releasing nutrients, providing aeration and aggregation of soil, as well as being an important food source for higher trophic level organisms. Even though earthworms are important, basing a soil CSCL on one species does not ensure protection to the entire soil community given the complex processes and interactions characteristic of functional soil communities.

Table 1. Selenium CSCLs in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Mammals	2.6E-04	mg/L water	Food web	River Otter	Ambrose et al., 1976
Birds	1.9E-02	mg/L water	Food web	Kingfisher	Heinz et al., 1987
Algae and Aquatic Plants	1.0E-01	mg/L water	Direct contact	*Scenedesmus obliquus*	Suter and Tsao, 1996
Freshwater Community					
Total	5.0E-03	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1995b
$Selenium^{4+}$	2.8E-02	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1995b
$Selenium^{6+}$	9.5E-03	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1995b
Amphibian (acute effects)	1.6E+00	mg/L water	Direct contact	Various amphibian species	Power et al., 1989; U.S. EPA, 1996
Terrestrial					
Mammals	2.1E+01	mg/kg soil	Food web	Raccoon	Rosenfeld and Beath, 1954
Birds	1.1E+01	mg/kg soil	Food web	American woodcock	Heinz et al., 1987
Mammals	1.1E+00	mg/kg plant tissue	Food web	Meadow vole	Rosenfeld and Beath, 1954
Birds	1.1E+01	mg/kg plant tissue	Food web	Northern bobwhite	Heinz et al., 1987
Plant Community	1.0E+00	mg/kg soil	Direct contact	Sorgrass	Efroymson et al., 1997a
Soil Community	7.0E+01	mg/kg soil	Direct contact	Soil invertebrates	Efroymson et al., 1997b

Ecotoxicological Profile for Ecological Receptors
Silver

This ecotoxicological profile on silver contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (3) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of silver so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

Silver is a rare, naturally-occurring, metallic element. Its average abundance is only about 0.3 ppm in natural soils (Clement Research Corp., 1994a) and about 0.09-0.55 µg/L in natural waters (U.S. EPA, 1985d). Silver occurs in elemental and ionic forms (i.e., 1+, 2+, and 3+ valence states). The mobility of silver in the environment depends on its physical and chemical form, as well as, physico-chemical conditions in surrounding media (e.g., soil, sediment, and water). Silver, released to the atmosphere from industrial sources in aerosol form, may be transported long distances, often more than 100 km. In water, silver is found as a free monovalent ion, as part of a chloride or sulfide compound, or adsorbed onto particulate matter. The bioavailability of silver in soils is largely dependent on environmental factors such as drainage, oxidation-reduction potential, pH, and organic matter content. Silver has been shown to bioconcentrate, although the potential for biomagnification through the food chain is low (Clement Research Corp., 1994a).

Silver toxicity in animals has been suggested by a number of studies. Acute and long-term exposure to silver in drinking water may have adverse effects in mammals (Clement Research Corp., 1994a; IRIS, 1996, EPA, 1992-1996; U.S. EPA, 1985d). Chronic exposure by ingestion may result in shortened life span or growth depression (U.S. EPA, 1985d). Silver, in a free ionic form, is highly toxic to the aquatic and benthic community (including amphibians); however, plants and mammals demonstrate fewer adverse effects from silver exposure. Not data were identified to evaluate the potential impact to avian species and the soil community. Neither carcinogenic nor mutagenic effects are suggested from silver exposure IRIS, 1996, (U.S. EPA, 1992-1996).

II. Geochemistry of Silver in Various Ecological Media

General

The background concentration of silver in surface water is typically below 10 parts per trillion (ppt) (total silver); in soil and sediments, the typical silver concentration is less than 0.2 parts per million (ppm). This discrepancy in silver concentrations is not surprising since the log partition coefficient (K_d) for silver ranges from 4.4 to 6.6. These high K_d values reflect an extremely strong particle affiliation for silver, and field studies indicate that silver released into the environment will be predominantly in a particulate form.

The behavior of silver in the environment depends on the specific geochemistry of the ecosystem as defined by a number of characteristics such as: the pH, the concentration of competing constituents (e.g., other metals), the availability of inorganic constituents to react with silver (e.g., sulfide and chloride ions), the concentration of dissolved organic matter, and the concentration of total suspended solids (TSS). These characteristics directly influence the partitioning of silver between particles and soluble species and, ultimately, determine the fraction of free ionic silver (Ag^+) to which biota are exposed.

Silver in Soils

Typical concentrations for silver in soils from different environments range from 0.1 to 5 mg silver/kg soil in uncontaminated areas (Kramer et al., 1994). Relatively little information is available for silver concentrations in natural soils, but the data available indicate that background (i.e., uncontaminated) levels are generally 0.1 to 0.2 µg/g or less. Log K_d values range from 2.2 to 5.1, illustrating a 3 order-of-magnitude range for this parameter. There is a strong affinity between silver and soil organic matter, and surface enrichments of silver are observed in uncontaminated soil profiles that closely parallel organic matter (e.g., humic and fulvic acids) (Jones et al., 1986). Similar surface enrichments are found for contaminated soils with elevated silver concentrations. In addition, various lines of evidence (sequential leaching studies, adsorption experiments, observations of increased silver mobility after organic matter degradation, etc.) suggest that organic-bound soil silver may represent a significant proportion of the total silver component in these surface soil horizons and plays an important role in controlling the cycling, mobility, and behavior of silver in soils (e.g., Jones and Peterson, 1986; Jones et al., 1986, and references therein; Szabo et al., 1995). Experiments that subject silver-bearing soils to leaching under simulated real environmental conditions (e.g., rainfall) suggest that silver is retained in near-surface soil horizons rather than being remobilized to greater depth (Jones et al., 1986).

- Usually have a high capacity to bind silver
- Organic-bound silver very important
- Insoluble forms predominate
- Concentrated in surface soil layers; not readily mobilized

The general behavior of silver in soils can be summarized as follows:

- Silver partitions preferentially into the particulate phase (soil-water distribution coefficients [K_ds] are limited but generally high) and forms a variety of organic-inorganic solids.

- Field and experimental data show silver tends to be enriched in near-surface soils and is not readily remobilized into solution (i.e., an insoluble form of silver predominates in soils).

For soils, silver tends to be enriched in the upper soil horizon (surface soil), and insoluble organic complexes are believed to be the dominant species for most soil types. Although remobilization of sorbed silver is possible, field and experimental data indicate that silver tends to stay bound to soil organic matter. Surface soil serves as an important sink for silver released into the environment.

Silver in Surface Waters

For surface waters, most of the silver will be associated (e.g., precipitated, adsorbed) with TSS, classically defined as particles that will not pass through a 0.45-µm filter. Silver in the filtrate (i.e., passing through the 0.45-µm filter) is typically referred to as “dissolved” silver and includes colloidal-bound silver and soluble silver complexes as well as free silver ions. This feature of silver behavior is particularly important in characterizing the ecological effects of silver since “dissolved” (colloidal and soluble) silver complexes are far less toxic to wildlife than free silver ions.

- Low background levels (<10 ng/L)
- Rapidly adsorbed to solids (log K_d: 4.4–6.6)
- Readily forms stable organic and inorganic complexes
- “Dissolved” (<0.45 µm) includes colloidal (20 to >90%), soluble complexes, as well as Ag^+
- Sediments are important sink

In natural waters, silver can exist in the oxidation states (0) and (I), each of which can occur in both dissolved and particulate forms. From theoretical considerations, reduction to elemental silver can occur under reducing conditions, and laboratory investigations have demonstrated that photo reduction of particle-associated silver (I) may be important in surface waters. However, modeling efforts indicate that the silver (I) complexes and compounds will dominate in natural waters.

In solution, silver (I) occurs as the hydrated, “free” cation or reacts to form various charged and uncharged species. As for other trace metals, the reactions of silver in natural waters are determined by the pH, the ionic strength of the solution, the presence or absence of anoxic regimes, and the concentration of reaction partners and of other cations capable of competing with silver for the partners. Thus, the behavior of silver in a particular aqueous environment is determined by the specific geochemistry of that environment.

The details of the behavior of silver in aqueous environments, in terms of chemical speciation, are complex and determined by many factors. Nonetheless, we have a broad understanding of the processes controlling the aquatic geochemistry of silver. General conclusions on the occurrence of silver in surface water environments are as follows:

- Natural “background” total silver concentrations in surface waters tend to be low (<10 ng/L).

- Total silver concentrations range up to 1 to 2 orders of magnitude above background downstream levels from anthropogenic sources.

- Silver is rapidly adsorbed to a variety of solids but is desorbed only extremely slowly (Andren et al., 1995).

- Classically, silver in the water column is partitioned between two phases, suspended particles (generally >0.45 µm diameter) and dissolved (generally <0.4 µm).

- The “dissolved” phase (<0.45 µm) includes silver sorbed or complexed with colloidal particles (~0.1–0.45 µm) and soluble silver compounds.

- Soluble silver compounds (i.e., noncolloidal) include organic and inorganic complexes and free silver ions.

The forms of dissolved silver (soluble silver) in natural waters are determined by many factors, including the pH, the ionic strength of the solution, the presence or absence of anoxic regimes, and the concentration of reaction partners and of other cations capable of competing with silver for the partners. Along with organic-silver complexes, the association of silver with chloride and sulfide complexes in solution seems to be particularly important:

- Silver readily forms stable, soluble complexes in the presence of chloride (predominantly $AgCl^0$) or sulfide ions (predominantly HS^-, $Ag[HS]^0$), which decreases the available “free” ionic silver concentrations (Kramer, 1995).

- Thermodynamic equilibrium modeling, used to investigate the partitioning of silver between free ion and chloro-complexes, shows that free ion concentrations range from 47% “dissolved” silver present (SPM and chloride ion concentrations low) to <0.01% in marine systems (high chloride ion concentrations)(Gill et al., 1994).

- As with organic-silver complexes, these soluble chloride and silver complexes are less toxic than the free silver ion.

Silver in Sediments

For sediments, silver concentrations reflect the high affinity of silver for particulate matter. In general, sediments are an important sink for silver in any type of aquatic ecosystem (e.g., freshwater, marine). Although silver can be released from sediment into the aqueous phase, generally it is almost immediately precipitated back into the solid phase (e.g., silver sulfide).

A large body of measurements indicate that sediments are an important sink for silver in freshwater and marine environments. As discussed previously, silver partitioning between suspended sediment and water shows a very high K_d. The concentration of silver in sediments reflects this partitioning. The range of silver concentrations in various sediments from freshwater systems 0.13 to 0.65 mg silver/kg sediment.

The behavior of toxic metals in sediments near the sediment-water interface is important because dynamic chemical processes occurring in this environment can cause major transformations in speciation of metals that may cause them to be released back into solution and, hence, be available for uptake by organisms.

A number of field and laboratory studies have addressed the possibility of silver being released from sediments, particularly from iron sulfide, which is the main sulfide host for silver in sediments. Most of these studies indicate that, even if the silver is released from sediments into the water column, it is almost immediately readsorbed or reprecipitated back into a solid phase. For example, Wingert-Runge and Andren (1994) investigated the release of Ag (by desorption) from natural sediments (clay and estuarine sediment) into freshwater and marine conditions. Their study concluded the following:

- In freshwater, silver release from sediment was negligible.

- For estuarine waters, a small amount of silver was desorbed, the amount being greatly influenced by the chloride ion content and the pH.

- The released silver in estuaries is complexed by the chloride present, forming silver chloride species rather than free ionic silver.

Others (e.g., Crecelius and Leather, 1996) have measured the release of silver from silver-bearing marine sediments containing silver as the insoluble sulfide. A small amount of silver is released into the water (as silver sulfide is oxidized), but is thought not to be a significant source of concern.

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystem

Chronic and acute silver toxicity to freshwater organisms has been observed at concentrations in the ranges of 0.12 to 29 µg/L and 1.5 to 60 µg/L, respectively (Ag^+)(LeBlanc, 1984). The overlap of acute and chronic toxicity results may well be an artifact of experimental design in that feeding during chronic tests generates more organic matter, and silver has a strong tendency to bind to organic matter in a form that is relatively nontoxic to biota. Other forms of silver such as silver chloride and silver thiosulfate are also far less toxic to fish, with LC_{50} values 4 to 6 orders of magnitude greater than for silver nitrate (i.e., Ag^+). Similarly, the LC_{50} for the relatively insoluble silver sulfide is around 240,000 µg/L (Hogstrand et al., 1996; LeBlanc, 1984). Adverse chronic effects were observed in estuarine species exposed to Ag^+ from 0.02 to 92 µg/L (Klein-MacPhee et al., 1984; Mathew and Menon, 1983). Amphibians indicated early life stage toxicity at a similar concentration range as fish and aquatic invertebrates: acute toxicity at 10 to 240 µg/L and chronic toxicity from 0.1 and 7 µg/L (Birge and Zuiderveen, 1995; Power et al., 1989; U.S. EPA, 1996). Various species of algae showed growth inhibition within the range of 9.3 to 50 µg/L (Ghosh et al., 1990; U.S. EPA, 1980k).

Terrestrial Ecosystems

No studies demonstrating adverse chronic effects to reproductive and developmental endpoints were identified in mammals; however, no diminution of fertility was noted during a 2-year study of male rats exposed to 89 mg silver/kg-day. In mammals, the critical endpoint for silver exposure is argyria, a blue-grey skin discoloration that does not appear to have any adverse physiological effects. Oral exposures to rats over a 37-week period demonstrated weight loss at 222 mg silver/kg-day (ATSDR, 1990). One study identified neither gross terata nor growth abnormalities in developing embryos when eggs were injected with silver nitrate (Ridgeway and Karnofsky, 1952). In a greenhouse study, Hirsch (1996) observed borderline effects on the height of oat seedlings at a sludge-amended silver concentration of 120 mg Ag/kg (dry soil). Unspecified toxic effects were reported on plants at 2 mg Ag/kg soil, although the form of silver applied was not reported (Efroymson et al., 1997a).

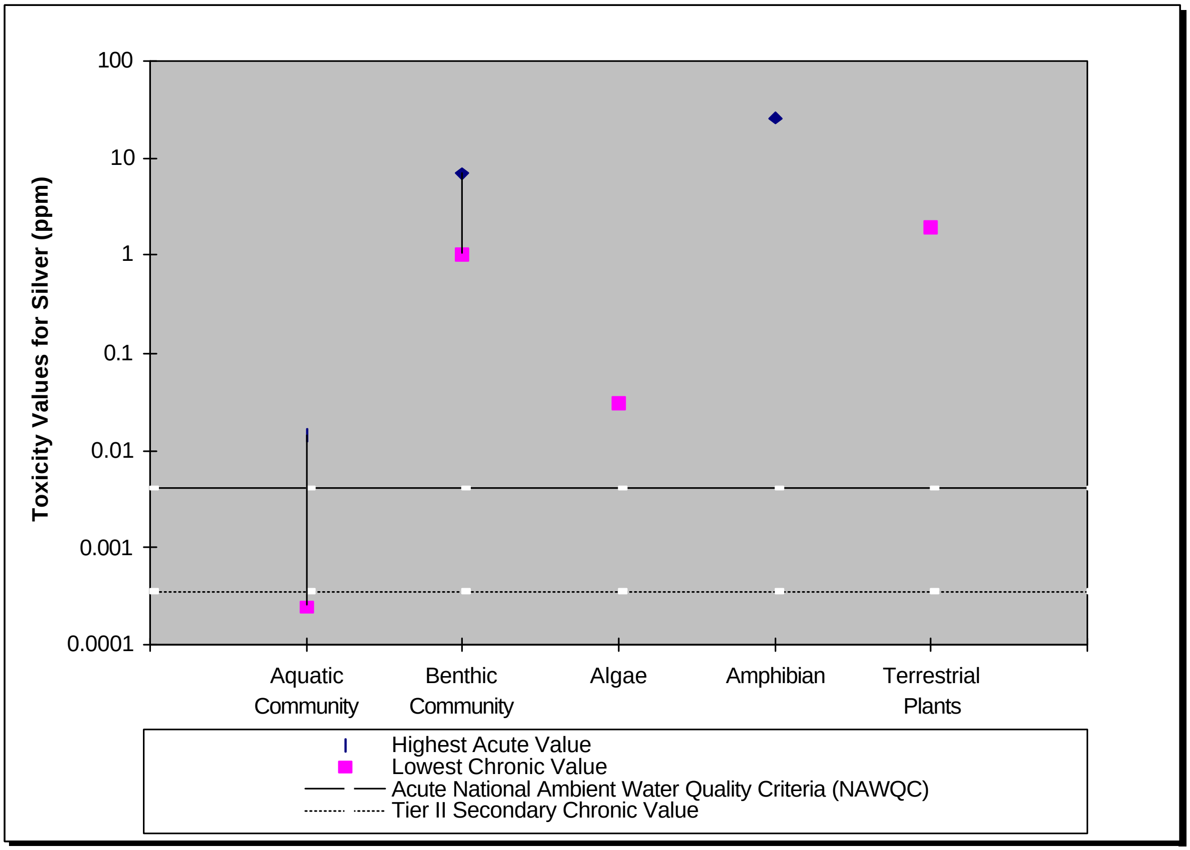

Figure 13: Silver: Effects Ranges for Ecological Receptors

IV. Characterization of Bioaccumulation

Freshwater Ecosystems

Algae bioconcentrate silver to a limited extent (bioconcentration factor [BCF].5 L/kg) but, once in the organism, silver is bound tightly to cell membranes and is unavailable to predators (Connell et al., 1991; Forsythe et al., 1996; Harris and Ramelow, 1990). Free ionic silver appears to bioaccumulate weakly in aquatic invertebrates (e.g., daphnid BCF=36 L/kg); however, other forms of silver such as silver thiosulfate or organo-silver complexes are bioaccumulated more efficiently by a number of aquatic species, including fish (Forsythe et al., 1996; Hogstrand et al., 1996). Although adverse effects related to free ionic silver are indicated in the literature, the implications of uptake and accumulation of complex silver ions or organo-silver compounds are not well understood. Regardless of the form of silver, it has not been shown to biomagnify in aquatic food chains (Wood et al., 1996b). Bioconcentration factor (BCF) of 0 L/kg was used for estimating food chain exposures to piscivorus mammals and birds. This is based on whole-body measured BCFs of bluegill sunfish (*Lepomis macrochirus*) with 28 days of exposure (Ag^{+}) (Barrows et al., 1980). As indicated by both Stephan (1993) and Barrows et al. (1980), concentration of silver in bluegill sunfish did not exhibit significant increase above that of the control.

Terrestrial Ecosystems
Some plant species have been shown to accumulate silver (e.g., lettuce, cattails), and a BCF for lettuce is estimated at approximately 0.01 mg Ag/kg plant per mg Ag/kg soil, assumed to be on a dry weight basis (Hirsch et al., 1993). However, the species of silver in the lettuce leaves was not determined. Sufficient data were not identified to determine bioconcentration factors (BCFs) for terrestrial vertebrates or terrestrial invertebrates, plants, and earthworms.

V. CSCL Development

When adequate benchmark values are identified, they are used to derive protective media-specific CSCLs as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor and the potential bioconcentration in prey, a protective concentration (i.e., CSCLs) in soil, plants or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. It is assumed that by protecting the more sensitive species, the other receptors are protected as well. However, no suitable studies have been identified to develop mammalian and bird CSCLs for silver.

Mammals: No suitable subchronic or chronic studies were identified which studied the effects of silver toxicity on reproductive or developmental endpoints in mammalian species.

Birds: No suitable subchronic or chronic studies were identified which studied the effects of silver toxicity in avian species.

Freshwater Community: A Final Chronic Value (FCV) was not available for silver. Therefore a Secondary Chronic Value (SCV) was estimated. For silver, a NAWQC was identified in the *Ambient Water Quality Criteria for Silver* (U.S. EPA, 1980k) for acute toxicity. The acute NAWQC for silver was based exclusively on silver nitrate studies (i.e., free ionic silver) and included data on 10 species of freshwater animals from 9 different taxonomic families. EPA indicated that the acute toxicity of silver apparently decreases as water hardness increases and used study data to develop the following expression relating acute toxicity to water hardness

$$NAWQC\ (\mu g/L) = e^{(1.72[\ln(hardness)] - 6.52)} .$$

Using this equation, the Final Acute Value (FAV) was determined to be 4.1 µg/L, normalized to a water hardness of 100 mg $CaCO_3$/L, a “typical” value for this mineral. The SCV was then estimated from the FAV of 4.1 µg/L as described in Suter and Tsao (1996). Acute-to-chronic ratios (ACR) for *Daphnia magna*, rainbow trout, and mysid shrimp (U.S. EPA, 1980k) were calculated at 2, 54, and 14, respectively. Per the tier II guidelines in EPA (60 FR 15366), a secondary acute-to-chronic ratio (SACR) of 11.5 was derived as the geometric mean of the three ACRs listed above. The SCV of 3.6E-04 mg/L for silver was then calculated by dividing the FAV by the SACR (Suter and Tsao, 1996). In this instance (e.g., given the complex speciation of silver), the ACRs were judged to be better than the default adjustment factor.

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metals concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). EPA has developed conversion factors (CFs) to estimate probable dissolved concentrations of metals in surface waters given a total metal concentration as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). A CF is not yet available for silver; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). The final surface water CSCL for silver is presented in Table 1.

Algae and Aquatic Plants: The CSCL for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or 2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). The aquatic plant benchmark for silver is 3.0E-02 mg/L based on growth inhibition of *Chlorella vulgaris* (Suter and Tsao, 1996). Since this CSCL was developed from a single toxicity study on algae, confidence in the CSCL is low.

Amphibians: No suitable subchronic or chronic studies were identified which studied the effects of silver toxicity on reproductive or developmental endpoints in amphibian species; however, several acute studies were identified characterizing silver toxicity. Review of data collected from seven experiments indicate that the acute toxicity of silver ranges from 0.0041 to 26 mg/L, with a geometric mean of 0.034 mg/L. Acute studies were conducted on various amphibian species (i.e., four amphibian species represented) during embryo and tadpole lifestages. Chemical exposures were conducted with silver nitrate resulting in free silver ions, the most toxic form of silver. The lowest acute value approximates the FAV determined for the freshwater community. Given the lack of chronic amphibian data, a CSCL of 0.034 mg/L was derived was based on acute toxicity. It should be noted that this CSCL is based on acute data; hence, exceedance of the CSCL indicates the potential for adverse effects (i.e., lethality). Investigations are ongoing to review the possibility of incorporating amphibian data into the NAWQC. Since amphibian species are more likely to breed in standing waters such as wetlands or ponds, the appropriateness of combining protective levels of amphibian receptors and the freshwater community is unclear at this time (Power et al., 1989; U.S. EPA, 1996).

Benthic Community- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, criteria are developed estimating the 10th percentile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). These values are not NOAA standards; rather, they are used to rank sites based on the potential for adverse ecological effects. A second criteria document evaluated for sediment CSCL development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the CSCL was changed. FDEP calculated the CSCL (i.e., threshold effects level, TEL) from the geometric mean of the 50th percentile of no effects data and the 15th percentile of the low effects data. The NOAA data, used in both documents, is based on total metal concentrations in sediments, and the toxicity endpoints were measured on species of amphipods, arthropods, and bivalves in addition to a variety of community-based endpoints (e.g., abundance, mortality, species composition, species richness). The FDEP criterion was chosen above the NOAA criterion for the following reasons; (1) the same database was used for both the NOAA criteria and the FDEP criteria development only different derivation methods were used; (2) in most cases, the FDEP criterion was more conservative than the NOAA criteria because a larger portion of the low effects data was used in benchmark development; (3) the marine TEL developed by the FDEP were found to be analogous to TELs observed in freshwater organisms (Smith et al., 1995).

The CSCL for silver was derived from 190 toxicity data points for low and no effects levels. For the screening level analysis of silver, the TEL of 7.3E-01 mg silver/kg sediment was selected as an appropriate sediment CSCL. Based on the quality and quantity of silver sediment data, the degree of confidence in the TEL value for silver was considered high (MacDonald, 1994).

Terrestrial Plants: As presented in Efroymson et al. (1997a), phytotoxicity benchmarks were selected by rank ordering the lowest observable effects concentration (LOEC) values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the benchmark. Such LOECs applied to reductions in plant growth, yield, or seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. An abstract by Hirsch (1996) indicated an LOEC of 120 mg Ag/kg for oat seedling height in a greenhouse study of sludge-amended soil. Although a sludge-amendment study of this type is very appropriate to develop a plant benchmark for silver, the abstract provided extremely limited information on the methods used or the ecological significance of the effect, thus this study could not be used. Another proposed benchmark for phytotoxic effects of silver in soils is based on a LOEC of 2 mg/kg, which resulted in unspecified toxic effects on plants (Efroymson et al., 1997a). Since the CSCL was based on a single study, reported unspecified effects, and did not indicate the form of silver applied to test soils, this benchmark study was not appropriate for CSCL development. No further studies were identified, so no CSCL could be developed for the terrestrial plant community.

Soil Community: Adequate data with which to derive a silver benchmark protective of the soil community were not available.

Table 1. Silver CSCL in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Algae and Aquatic Plants	3.0E-02	mg/L water	Direct contact	*Chlorella vulgaris*	Suter and Tsao, 1996
Freshwater Community					
Total	3.6E-04	mg/L water	Direct contact	Aquatic biota	Suter and Tsao, 1996
Benthic Community	7.3E-01	mg/kg sediment	Direct contact	Benthos	MacDonald, 1994
Amphibian (acute effects)	3.4E-02	mg/L water	Direct contact	Various amphibian species	Power et al., 1989; U.S. EPA, 1996

Insufficient data for birds, mammals, plants, and the soil community.

Toxicological Profile for Selected Ecological Receptors
Vanadium

This ecotoxicological profile on vanadium contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (5) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of vanadium so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Introduction

Vanadium may be present in over 50 different mineral ores and in association with fossil fuels. Vanadium is released to the environment naturally through the weathering of parent materials. It may also be released anthropogenically through the leaching of ore and clay residuals, ash, slags, urban sewage sludge, and certain fertilizers. Once released to the environment, vanadium biogeochemical cycling is dominated by the vanadyl/vanadate (V^{4+} / V^{5+}) redox couple.

- Vanadium has six oxidation states (-1, 0, +2, +3, +4, and +5), the most common of which are the +3, +4, and +5 states.
- The mobility and biogeochemical cycling of vanadium is governed by the redox behavior of V^{4+} / V^{5+}.

II. Geochemistry of Vanadium in Various Ecological Media

Vanadium in Soils

Vanadium is found throughout the earth's crust at an average concentration of 150 mg/kg. The concentration of vanadium measured in soil is closely correlated to the parent rock type. A range of 3 to 310 mg/kg has been observed. The average vanadium content in soils in the United States is 200 mg/kg.

- Literature describing the geochemical behavior of vanadium in soils is limited and little pertinent data are available.

Literature describing the geochemical behavior of vanadium in soils is limited and little pertinent data are available (EPRI, 1984). Wehrli and Stumm (1989)[2] indicate that the vanadyl/vanadate (V^{4+} / V^{5+}) redox couple dominates vanadium biogeochemical cycling in natural waters. This is consistent with information reported in EPRI (1984): at pH values less than or equal to 8, the V^{4+} and V^{5+} valence states are dominant under oxidizing conditions.

[2] Wehrli, Bernhard and Werner Stumm. 1989. Vanadyl in natural waters: Adsorption and hydrolysis promote oxygenation. Geochim. Cosmochim. Acta. 53, 69-77.

Wehrli and Stumm (1989) indicate that both the vanadate and vanadyl species are known to sorb to mineral and biogenic surfaces. EPRI (1984) report that the distribution of vanadium in soils closely follows the distribution of iron and secondary iron oxides in soils, thus indicating their importance as adsorbents for vanadium. In the presence of humic acids, the mobile vanadate anions may be converted to the immobile vanadyl cations resulting in local accumulations of vanadium.

Vanadium in Surface Water

Measurements of vanadium in fresh water systems range from 0.3 to 220 Fg/L. Measured concentrations of vanadium in rivers in the Colorado Plateau ranged up to 70 Fg/L. Concentrations ranged from 30 to 220 Fg/L in Wyoming rivers. These higher concentrations reflect the presence of naturally occurring uranium ore that contributes vanadium to the system.

C Vanadium may be present in surface water in either the dissolved phase or adsorbed to particulate matter. It has been estimated that the majority of vanadium in surface water is associated with the particulate matter.
C $H_2VO_4^-$ and HVO_4^{2-} are common species under oxidizing conditions.
C VO^{2+} and $VO(OH)^+$ are common species under reducing conditions.

Vanadium may be present in surface water in either the dissolved phase or adsorbed to particulate matter suspended in the water column. Vanadium generally exists as $H_2VO_4^-$ and HVO_4^{2-} under oxidizing conditions and as VO^{2+} and $VO(OH)^+$ under reducing conditions.

The vanadate and vanadyl species are known to sorb to mineral and biogenic surfaces (Wehrli and Stumm, 1989). If the suspended particulate load is high, vanadium will likely be adsorbed to particulate matter. It has been estimated that only 13 percent of vanadium is transported via surface water bodies in solution, rather the majority of it (87 percent) is transported via suspension.

Vanadium in Sediments

Vanadium partitioning between water and sediment is strongly influenced by the presence of particulates in the water column. Ferric hydroxides and organic matter constitute the main sorbents of vanadium in the sedimentation process. As these particles settle out of solution, vanadium is removed from the water column and concentrated in the underlying sediments.

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystems

Vanadium has been found to be mildly toxic to aquatic organisms, and toxicity is largely independent of pH and water hardness ($NaVO_3$; V^{5+}) (Hamilton and Buhl, 1990). Hamilton and Buhl (1990) reported a 96-hour LC_{50} of 16,500 µg/L for chinook salmon fry. Toxicity may be influenced by the interactions of other toxic trace metals (Hamilton and Buhl, 1990; Venugopal and Luckey, 1978). Exposure for aquatic organisms could occur through ingestion of contaminated food, water, or sediments, or through direct contact with contaminated media. Acute toxicity to invertebrates is indicated in the range of 1.5 to 3.3 mg/L while fish indicated acute toxicity in the range of 0.17 to 16.5 mg/L (Suter and Tsao, 1996). No data characterizing adverse effects to algae or amphibians were identified.

Terrestrial Ecosystems
Vanadium in toxic doses may affect the nervous, cardiovascular, respiratory, and gastrointestinal systems and cause death (Venugopal and Luckey, 1978). Inhalation exposure to vanadium can cause respiratory effects, and oral exposures have been found to have deleterious effects on the gastrointestinal system (Domingo et al., 1986). Oral administration of between 92 and 368 ppm diet to the food of experimental animals reportedly reduced voluntary food intake to the extent this behavior induces starvation (Browning, 1969). Chronic oral exposure to vanadium has resulted in maternal toxicity, embryotoxicity, and teratogenicity in rats and mice, and depressed growth in chickens (Domingo, 1994; Paternain et al., 1990; Venugopal and Luckey, 1978).

IV. Bioaccumulation Potential

Freshwater Ecosystems
The danger of vanadium bioconcentration and bioaccumulation appears to be low, as vanadium has not been found to concentrate to a great extent in most organisms (V2O5; V2+) (Holdway et al., 1983; Clement Associates, 1990b). Wren et al. (1983) measured vanadium concentrations in lake sediments and wildlife in an undisturbed region of Canada (chemical form unspecified). The vanadium content of the sediment (63 to 139 ppm) was within normal background level, and they found no evidence of biomagnification of vanadium in any aquatic animal collected from the lake or in any terrestrial animal collected from the surrounding area. Vanadium was detected at very low levels in the tissues of clams, bluntnose minnows, and fish-eating birds; at a detection limit of 0.1 ppm, vanadium was not detected in fish and other mammals. No sufficient data were identified to determine a whole-body bioconcentration factors (BCFs) for vanadium in fish,
aquatic invertebrates, and plants.

Terrestrial Ecosystem

The danger of vanadium bioconcentration and bioaccumulation appears to be low, as vanadium has not been found to concentrate to a great extent in most organisms (Holdway et al., 1983; Clement Associates, 1990b). Vanadium is probably present in all terrestrial animals, but is often below detection limits. Plant uptake depends on soil and growing conditions, but vanadium concentrations in aboveground parts are low for most species. Certain plants, however, such as the legume *Astralagus preussi* and the mushroom *Amanita muscaria*, readily accumulate vanadium (Clement Associates, 1990b). Sufficient data, however, were not identified to determine bioconcentration factors for terrestrial vertebrates, invertebrates, plants, and earthworms.

V. CSCL Development

The benchmark values presented in this section for mammals and birds were used to derive protective media-specific CSCLs as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor and the potential bioconcentration in prey, a protective concentration (i.e., CSCLs) in soil, plants or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. It is assumed that by protecting the more sensitive species, the other receptors are protected as well.

Mammals: A chronic study was identified in which female Sprague-Dawley albino rats were given sodium metavanadate intragastrically at doses of 5, 10, or 20 mg $NaVO_3$/kg-day for 14 days prior to mating, during gestation, and for 21 days following delivery of the pups (Domingo et al., 1986). Male rats were also given sodium metavanadate for 60 days prior to

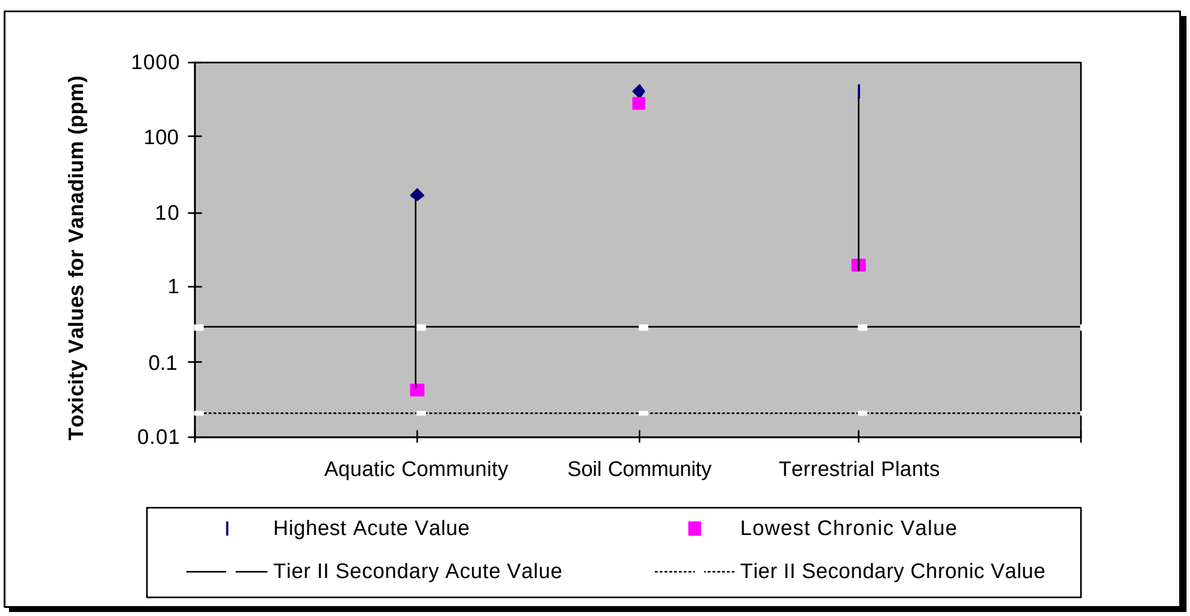

Figure 14: Vanadium: Effects Range for Selected Ecological Receptors

mating. At a 5 mg $NaVO_3$ /kg-day dosage, the length and body weight of the rat pups nursed by vanadium-treated mothers was significantly lower than the controls. Domingo et al. (1986) reported a lowest LOAEL of 5 mg/kg-day, at which significant developmental impairments were observed in the pups in vanadium-treated groups. Because a relevant NOAEL was not identified in the study, the LOAEL was divided by 10 to estimate the NOAEL value. The Domingo et al. (1986) study was selected for the benchmark because: (1) doses were administered over a chronic duration via oral ingestion; (2) the study focused on reproduction as a critical endpoint; (3) it found the lowest LOAEL in the data set; and (4) it investigated the toxicity effects of vanadium on rats, which are a particularly sensitive test species.

In another study, a significant decrease in fetal body weight was noted in litters born from albino Swiss mice exposed to a single intra-peritoneal injection of 25 mg sodium metavanadate/kg on gestation day 12 (Bosque et al., 1993). The Bosque et al. (1993) study was not considered suitable for the derivation of a mammalian benchmark because the dose was administered by an exposure route (intra-peritoneally) that is not relevant to expected environmental exposure pathways.

Birds: Only one study investigating the effects of vanadium toxicity in avian species was identified. Romoser et al. (1961) fed 7-day-old male chicks a diet containing vanadium as a calcium salt from days 7 through 28. A depression in the rate of weight gain was observed at doses greater than 20 ppm, indicating a NOAEL of 20 ppm for growth effects. No information on daily food consumption rates were provided. The use of an allometric equation for food consumption in chickens was required to convert doses from dietary ppm to mg/kg-day (U.S. EPA, 1988a):

$$\textit{Food consumption (kg/day)} = 0.0582(W^{0.651})$$

where W is body weight in kilograms. The geometric mean of the body weights of 1 week and 4 week old Vantress x Arbor Acre male chicks was estimated to be 0.487 kg (Parkhurst, 1995). The calculated food consumption rate of 0.041 kg/day and the dietary dose of 20 ppm described in the study were used to estimate a daily dose of 1.68 mg/kg-day. The value was then scaled for species representative of a freshwater ecosystem using the cross-species scaling algorithm adapted from Opresko et al. (1994). Since the Romoser et al. (1961) study documented effects of vanadium exposure to male chicks, mean male body weights of the representative species were used in the scaling algorithm to obtain the toxicological benchmarks. No additional avian toxicity studies were identified for species representing the terrestrial ecosystem. Thus, for avian species in the terrestrial ecosystem, the NOAEL of 1.5 mg/kg-day from the Romoser et al. (1961) study was used as the benchmark value.

Freshwater Community: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria (NAWQC) published by the EPA Office of Water. Neither of these criteria have been developed for vanadium; therefore, a Secondary Chronic Value (SCV) was calculated. SCVs are calculated by analogous methods used to derived FCVs for both the GLWQI and NAWQC. However, when the eight data requirements for developing the FCV were not available, the SCV criteria was based on one to seven of the eight required criteria. For vanadium, the SCV of 2.0E-02 mg/L developed by Suter and Tsao (1996) for total vanadium was selected as the appropriate CSCL to use in this analysis. The SCV for vanadium was derived from 25 data points derived from toxicity endpoints found in fish and aquatic invertebrates. From these data, an SAV of 0.284E-01 mg/L and SACR of 14.29 were calculated. The resulting ratio of these values (i.e., SAV/SACR) determined the SCV of 2.0E-02 mg/L (Suter and Tsao, 1996).

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metals concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). EPA has developed conversion factors (CFs) to estimate probable dissolved concentrations of metals in surface waters given a total metal concentration as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). A CF is not yet available for vanadium. This adjustment reflects the current Agency position on criteria development and regulatory application of metals; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). The final surface water CSCL for vanadium is presented in Table 1.

<u>*Amphibians:*</u> No suitable subchronic, chronic, or acute studies were identified for CSCL development which studied the effects of vanadium toxicity on reproductive, developmental, or mortality endpoints in amphibian species.

<u>*Algae and Aquatic Plants*</u>: Relevant endpoints for aquatic plants focused on the ability of plants to support higher trophic levels as well as the ability to provide habitat for other species in the freshwater ecosystem. The benchmarks for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or 2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum capricornutum*). No CV was reported for vanadium and, therefore, no benchmark was developed.

<u>*Benthic Community*</u>- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, CSCLs are developed estimating the 10th percentile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). For our purposes, the ER-L was considered an appropriate benchmark for freshwater sediment biota. A second criteria document evaluated for sediment criteria development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the criteria was changed. Neither of these documents, or alternative references such as ORNL, developed a suitable sediment benchmark for vanadium; therefore, no benchmark on vanadium could be developed.

<u>*Terrestrial Plants*</u>: As presented in Efroymson et al. (1997a), phytotoxicity benchmarks were selected by rank ordering the lowest observable effects concentration (LOEC) values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the benchmark. Such LOECs applied to reductions in plant growth, yield, or seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. The proposed benchmark for phytotoxic effects of vanadium in soils is 2.0 mg/kg, based on the lowest LOEC presented by Efroymson et al. (1997a). Since the CSCL

was based on a single study reporting unspecified effects and did not indicate the form of vanadium applied to test soils or the terrestrial plant species exposed, this benchmark study was not appropriate for CSCL development. No further studies were identified, so no CSCLs could be developed for the terrestrial plant community.

Soil Community: Because no adequate data to develop community-based CSCLs were identified, CSCL for soil from microbial effects presented in Efroymson et al. (1997b) of 20 mg vanadium/kg soil was proposed; it is based on 10 reported effects on microbial activities from vanadium exposure. The toxicity endpoints measured in microorganisms included effects such as enzyme activities, nitrogen transformation, and mineralization. These functions have been recognized to play important roles in nutrient cycling, which provides nutrients in available forms to plants. Even though microbial processes are important in soil, using this CSCL may have limited utility. Basing a CSCL on only one species or taxa does not consider the complex processes and interactions characteristic of functional soil communities. Community-based CSCLs should be used as they become available. Confidence in this CSCL is low.

Table 1. Vanadium CSCLs in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Freshwater Community Total	2.0E-02	mg/L water	Direct contact	Aquatic biota	Suter and Tsao, 1996
Terrestrial					
Mammals	5.3E+01*	mg/kg soil	Food web	Raccoon	Domingo et al., 1986
Birds	3.1E+01*	mg/kg soil	Food web	American woodcock	Ramoser et al., 1961
Mammals	2.7E+00	mg/kg plant tissue	Food web	Meadow vole	Domingo et al., 1986
Birds	3.0E+01	mg/kg plant tissue	Food web	Northern bobwhite	Ramoser et al., 1961
Soil Community	2.0E+01*	mg/kg soil	Direct contact	Soil invertebrates	Efroymson et al., 1997b

Insufficient data for aquatic birds, aquatic mammals, terrestrial plants and benthic community

C This CSCL should not be used because it is below soil background concentrations (lowest mean background concentration 58 mg vanadium/kg soil). This exceedance may be an artifact of our back-calculation method for avian receptors(i.e., calculating media-specific CSCLs from the benchmark study). Secondly, the CSCLs exceeding for the plant and soil community is probably related to bioavailability. Toxicity experiments in the lab usually expose receptors to a more bioavailable form of the constituent giving a lower toxicity values to base the CSCLs on.

Ecotoxicological Profile for Ecological Receptors
Zinc

This ecotoxicological profile on zinc contains five sections: (1) background (e.g., background concentrations), (2) geochemistry of the constituent in various ecological media, (3) effects characterization, (4) bioaccumulation potential and (5) chemical stressor concentration limit (CSCL) development. The first four sections are intended to provide an overview of the environmental factors that influence the toxicological potential of zinc so that the limitations of the CSCLs may be better understood. The fifth section presents the rationale and development of CSCLs for the suite of ecological receptors used to represent aquatic and terrestrial ecosystems. The profile is intended to present the ecotoxicological CSCLs in a broader environmental context, so the ecological significance of the CSCLs may be properly interpreted.

I. Background

Zinc is a common, naturally-occurring metallic element. Zinc is found in soils of the United States in concentrations ranging from less than 5 ppm to 2900 ppm, with a mean concentration of 60 ppm (Dragun and Chiasson, 1991). In the environment, zinc occurs primarily in the +2 oxidation state. In unpolluted waters, zinc exists mostly in the hydrated divalent cationic form, and in polluted waters zinc often forms complexes with inorganic and organic ligands (ATSDR, 1994). The hydrated divalent cationic form of zinc is much more toxic to aquatic biota than zinc which is complexed with dissolved organic matter or with SPM or colloidal matter. Anthropogenic releases to the soil account for the greatest source of zinc to the environment (ATSDR, 1994). Although much of the zinc entering the environment eventually deposited in sediments, its mobility is dependent upon a variety of factors, including compound form, solubility, and pH. Bioconcentration in aquatic organisms is relatively high, though it is much lower in terrestrial organisms, and biomagnification does not occur in either terrestrial or aquatic food chains (ATSDR, 1994).

II. Geochemistry of Zinc in Various Ecological Media

<u>*Zinc in Soils*</u>

- ! In soils, the mobility of zinc depends on the species present and the physico-chemical properties of the soil.
- ! There is a complex relationship between the soil pH and the mobility of zinc.
- ! In anaerobic soils, zinc sulfide controls the mobility of zinc. As zinc sulfide is insoluble, the mobility of zinc is low.

The mobility of zinc in soils depends on the solubility of zinc species and on soil properties such as cation exchange capacity, redox potential, and pH (ATSDR, 1994 and references therein). A number of studies have investigated the relationship between soil pH and the mobility of zinc, or concentration of zinc in solution. The relationship is complex, most probably because pH is not the only factor influencing the behavior of zinc in soils. Saeed and Fox (1977; cited in ATSDR, 1994) showed that at pH < 7, there is an inverse relationship between pH and the amount of zinc in solution. Other workers reported that the mobility of zinc in soil increases at low soil pH in oxidizing environments and at low cation exchange capacities of soil (ATSDR, 1994 and references therein). Alternatively, other work showed that the amount of zinc in solution generally increases at pH > 7 in soils with high organic matter contents, probably as a result of the release of zinc complexed with organic matter, reduced zinc adsorption at higher pH, or increased concentration of chelating agents in the soil (ATSDR, 1994 and references therein). The relationship between zinc solubility and pH is non-linear in calcareous soils. At high pHs, zinc precipitates as $Zn(OH)_2$, $ZnCO_3$, or calcium zincate (Saeed and Fox, 1977, cited in ATSDR, 1994). Clay and metal oxides can adsorb zinc and tend to decrease the mobility of zinc in soils.

In anaerobic environments zinc sulfide controls the mobility of zinc (ATSDR, 1994). As zinc sulfide is insoluble, the mobility of zinc in anaerobic soils is low.

Ma and Rao (1997) investigated the chemical partitioning of heavy metals, including zinc (Zn) in contaminated soils. A sequential extraction procedure was used to fractionate the metals into operationally defined groups (water soluble, exchangeable, carbonate, Fe-Mn oxide, organic, and residual) which generally reflected decreasing solubility. Approximately 56-98% of the zinc in the soils was concentrated in the residual fraction. A significant proportion of zinc, ~2-44%, was present in non-residual fractions of the soil, suggesting that zinc was potentially more mobile and bioavailable than the other metals studied. The distribution of zinc between the different fractions was independent of the total zinc concentration of the soils. In contrast, the distribution of Cu, Cd, and Ni in different fractions was dependent upon the total metal concentration in the soil.

Zinc in Surface Waters

Zinc is relatively mobile in the aqueous environment. In natural waters, zinc can exist as the hydrated ion, as inorganic complexes, and as organic complexes.

- ! Zinc is relatively mobile in aqueous environments.
- ! Zinc can exist as the hydrated ion, inorganic complexes and organic complexes in natural waters.
- ! The behavior of zinc is controlled primarily by geochemical processes, and is heavily dependent on the balance between complexation with dissolved organic matter and association with SPM and colloidal matter;

In rivers, the behavior of zinc is primarily controlled by geochemical processes (Hart and Hines, 1995). Zinc behavior is heavily dependent upon the balance between complexation with dissolved organic matter and association with suspended particulate matter (SPM) and colloidal matter. Biological processes have only a minor influence on its behavior.

Shafer et al. (1997) determined that the partitioning behavior (between dissolved (< 0.4 Fm) and particulate (> 0.4 Fm) phases) characteristic of zinc in two Wisconsin rivers appeared to show an intermediate affinity for both dissolved organic carbon, DOC, and clays. Comparing the characteristic behavior of lead (Pb), zinc (Zn), cadmium (Cd), and copper (Cu), partitioning of the metals to SPM followed the trend Pb>Zn>Cd>Cu and their association with DOC appeared to follow the trend Cu>Cd>Zn>Pb (Shafer et al., 1997).

A study of the effect of pH on zinc mobilization in highly acidic (pH # 3.6) lakes showed elevated zinc concentrations in the water column, and substantially lower zinc concentrations in the upper layers of the underlying sediment than reported for higher pH lakes (Sprenger et al., 1987; White and Discoll, 1987, cited in ATSDR, 1994). Elevated zinc concentrations in the water column compared to the sediment were believed to result from reduced adsorption of zinc onto oxide surfaces at low pH, solubilization of inorganic zinc from the sediment, and the dissociation of sediment bound organic zinc complexes and their subsequent release into solution.

Zinc in Sediments

> ! In sediment, the behavior of zinc is primarily controlled by the pH and physical properties of the sediment.
>
> ! Various studies have demonstrated that dissolved organic matter, phosphates, and iron hydroxides can also play a role in controlling the mobility of zinc in soils.

The behavior of zinc in sediment is governed primarily by the pH and physical properties of the sediment. Sediments in reservoirs downstream of lead-zinc mining and milling areas were found to concentrate zinc compared to the surrounding soils (Pita and Hyne, 1975, cited in ATSDR, 1994). Moreover, the zinc content of the sediments was related to their depth, organic matter content, and clay content. Phosphates and iron hydroxides were shown to play a role in transferring zinc from river water to sediments in a study by Houba et al. (1983, cited in ATSDR, 1994) which showed that zinc was bound mostly to carbonate and amorphous matter (iron, aluminum, and manganese hydroxides). In acidic sediments, more zinc is available in ionic form, and cation exchange processes influence its fate. Depending on the nature and concentrations of other mobile metals in sediments, competition for binding sites probably occurs. In the absence of suitable binding sites, zinc may be mobilized. Leaching experiments using sediment from the Rhone River showed that dissolved organic matter and pH controlled zinc adsorption and mobility (ATSDR, 1994 and references therein).

Zinc is desorbed from sediments with increasing salinity, as the adsorbed zinc is displaced by alkali and alkaline earth cations which are abundant in saline waters (ATSDR, 1994 and references therein).

III. Effects Characterization

This section, along with the bioaccumulation potential section, are subdivided to evaluate receptors of the freshwater and terrestrial ecosystems separately. Figure 1 summarizes the range of effects data for receptors of concern illustrating the sensitivity of various taxa to exposure. For reference, the water quality standards for freshwater communities (NAWQC or secondary values) are included for both acute and chronic endpoints. These values can be disregarded for receptors in the terrestrial community, because the NAWQC only provides protection for aquatic receptors not predators of aquatic biota. NAWQC provide a context for effects ranges in the aquatic community.

Freshwater Ecosystems

Zinc's toxic effects in freshwater ecosystems include decreased growth rates, respiratory disruption, and reproductive impairment; the effects extend to a wide range of plant and animal species. In fish, high zinc concentrations and short exposures tend to be associated with damage to the gills whereas chronic exposures primarily result in damage to reproductive functions (Zn^{2+})(Eisler, 1993). Fish are among the more sensitive biota in freshwater environments. For example, fry of brown trout (*Salmo trutta*) exposed to 4.9 μg/L of zinc were all dead after 18 days of exposure. Blue green algae have been reported to have adverse effects at concentrations in the range of 19 to 823 μg/L. Freshwater insects such as mayflies, stoneflies and caddisflies are relatively tolerant to zinc exposure generally at concentrations greater than 1330 µg/L. Environmental conditions, such as low dissolved oxygen concentrations, decreased organic content, and high sodium concentrations, influence the toxicity of zinc. Acute effects (LC_{50}s) to amphibian species are indicated in the range of 0.01 to 155 mg/L (U.S. EPA, 1996).

Terrestrial Ecosystems

Because zinc is essential for growth and reproduction, mammals are relatively tolerant to high intake rates of zinc sometimes up to levels 100 times greater than the minimum recommend daily requirement (Eisler, 1993). The primary toxic effects of zinc is on zinc-dependent enzymes which regulate RNA and DNA. Chronic dietary exposures ranging from 500 mg/kg diet and above for more than 3 weeks resulted reduced sperm production, forelimb lameness, and retarded growth in laboratory rats (Eisler, 1993). At 6,820 mg/kg dietary exposures for 13 weeks, altered appetite and tissue damaged were evident in rats. Oral exposures of 6,820 mg/kg diet in mice results in adverse effects of survival, growth, and blood chemistry; additionally, lesions have also occurred in stomach, intestine, and kidney (Eisler, 1993). Mallard duck fed 3,000 mg/kg for 15 to 30 days resulted in diarrhea after 15 days; suffered leg paralysis, decreased food consumption and high mortality (Eisler, 1993). Terrestrial plants show effects to growth in the range of 3.3 to 1000 mg/kg soil, but in some species no effects were evident in the range of 10 to 474 mg/kg soil (Efroymson et al., 1997a). Data suggest that soil biota are affected at concentrations of 136 to 5000 mg/kg soil (Efroymson et al., 1997b).

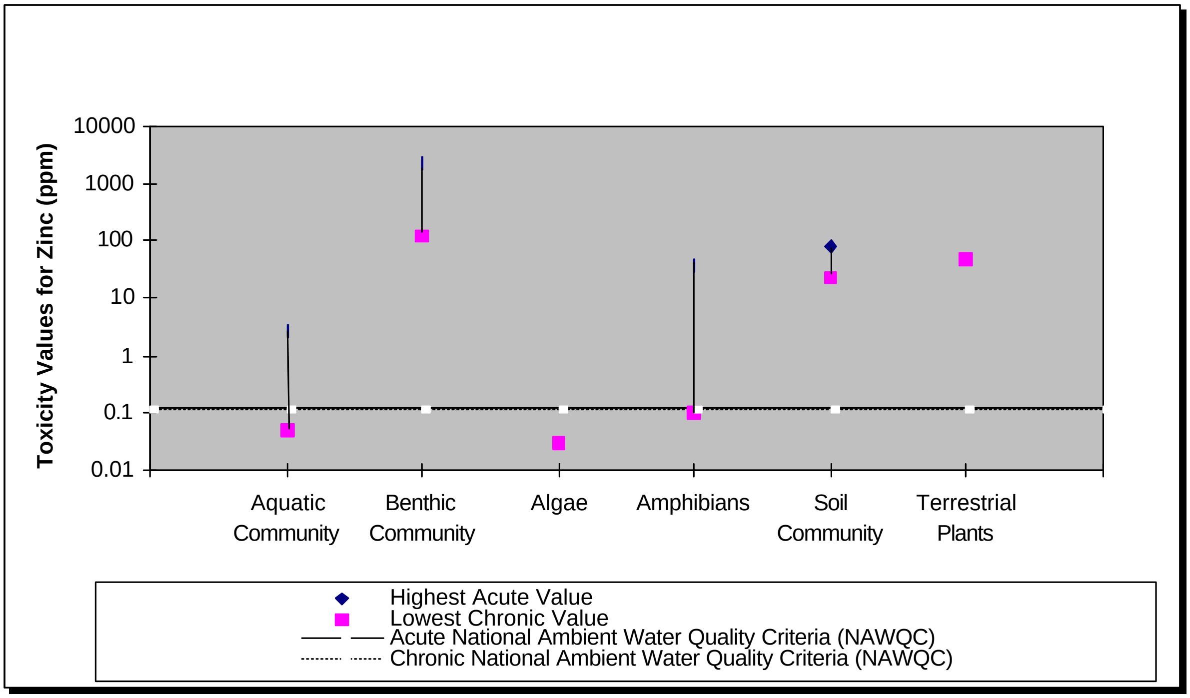

Figure 15: Zinc: Effects Ranges for Selected Ecological Receptors

IV. Bioaccumulation Potential

Freshwater Ecosystems

Bioconcentration factors seems to decrease at higher trophic levels. In experiments where accumulation of zinc was tested individually for each organism, bioconcentration factors (BCFs) ranged from 1,530 to 16,600 for algae; 107 to 1,130 for insects ; and 51 to 432 for fish. No data on accumulation of benthic biota have been identified.

A BAF value of 4.4 (L water/kg tissue) is used for estimating food chain exposures to piscivorus mammals and birds. This value is the geometric mean of 2.45 and 8.03 Stephan 1993) has cited from Murphy et al. (1978). Bioconcentration factors (BCFs) of 130 and 130 of 3-spine stickleback (*Gasterosteus acul*) and 9-spine stickleback (*Pungitius pungitius*), respectively. Although these are whole-body measured BCFs, these values were not used for the following reasons: (1) they were conducted in sea water; the chemical speciation and bioavailablility is much different in salt water than freshwater; (2) BAFs are much preferred than BCFs. Additional data on zinc identified in the future may provide further confirmation on bioaccumulation factors.

Terrestrial Ecosystems

Bioaccumulation in terrestrial invertebrates, plants, and small mammals is currently being investigated at Oak Ridge National Labs. Bioaccumulation and bioconcentration factors (BAFs and BCFs) for terrestrial plants, invertebrates, and small mammals have been proposed from review of primary literature sources. The 90th percentile of the bioaccumulation data for these receptors derived from both laboratory and field studies were used to determine terrestrial food chain exposures. For earthworms, a BAF of 13 was proposed for zinc based on 244 data points. No BCFs were proposed for terrestrial plants. For small mammals, based on 103 reported values assessing the transfer of zinc from soil to small mammals, a BAF of 2.7 was proposed (Sample et al., 1997; Samples et al., 1998). These values were used to model food chain exposures to terrestrial species for this analysis, because currently, they stand as the most comprehensive collection of bioaccumulation data for terrestrial ecological receptors (Sample et al., 1997; 1998a; 1998b).

V. CSCL Development

The benchmark values presented in this section for mammals and birds were used to derive protective media-specific CSCLs as outlined in the stressor-response profile methodology (i.e., analysis phase of ERA). By scaling the benchmark study by body weight to a representative wildlife receptor (e.g., rat study extrapolated to a shrew), determining the dietary preferences of wildlife receptor and the potential bioconcentration in prey, a protective concentration (i.e., CSCLs) in soil, plants or surface water was developed. Since CSCLs for receptors other than mammals and birds were already in media concentrations, this same derivation process was not required. A summary table of CSCLs are provided in Table 1. Although CSCLs were developed for numerous wildlife receptors of both the aquatic (e.g., otter, mink, and great blue heron) and terrestrial ecosystems (e.g. shrew, fox, and hawk), only the lowest CSCL is presented in Table 1. It is assumed that by protecting the more sensitive species, the other receptors are protected as well.

Mammals: Schlicker and Cox (1968) fed female rats diets amended with 0.2% and 0.4% zinc as zinc oxide for 21 days prior to mating and up until a fetal age of 15 days. They observed an increased percentage of fetal resorptions in the 0.4% zinc diet group; fetal development was normal for mothers fed 0.2% zinc. This resulted in a NOAEL dose of 0.2% for reproductive effects. Conversion of this dose to a daily dose in units of mg/kg-day required the use of the allometric equation presented above for food consumption rate in laboratory mammals (Opresko et al., 1994). An average (0.174 kg) of the reported body weights of the test species, the calculated food consumption rate of 0.018 kg/day, and the percentage of zinc oxide in the diet were used to derive a NOAEL of 207 mg/kg-day. The NOAEL from the Schlicker and Cox (1968) study was selected to derive the toxicological benchmark because: (1) doses were administered over a chronic duration and via oral ingestion, an ecologically significant exposure pathway; (2) the study focused on reproductive toxicity as a critical endpoint; and (3) it contained adequate dose-response information.

Samanta and Pal (1986) studied the effects of 4,000 ppm of zinc as zinc sulfate fed to male rats. After 30 to 32 days of exposure at this dose level, male rats exhibited decreased sperm motility and reduced fertilizing capacity, resulting in a LOAEL of 4000 ppm. Conversion of this ppm dose level to a daily dose in units of mg/kg-day required the use of an allometric equation to estimate daily food consumption for laboratory mammals (U.S. EPA, 1988a):

$$\textit{Food consumption (kg/day)} = 0.056(W^{0.6611})$$

where W is body weight in kilograms. Using the reported body weight of 0.162 kg, the calculated food consumption rate of 0.017 kg/day, an estimated LOAEL of 420 mg/kg-day was calculated for reproductive effects. In another study, Bleavins et al. (1983) exposed male and female mink to 1000 ppm zinc as zinc sulfate for 25 weeks. The mink were mated after 8 to 11 weeks. The dose had no effect on the length of the gestation period or litter size. However, the male offspring of the dosed females exhibited reduced growth rate. This resulted in a LOAEL of 1000 ppm for developmental effects. Conversion of this ppm dose level to a daily dose in units of mg/kg-day required the use of an allometric equation to estimate daily food consumption for mammals (Nagy, 1987):

$$Food\ consumption\ (g/day) = 0.235(W^{0.822})$$

where W is body weight in grams. Using an estimated body weight for mink of 1020 g (male-female average), the calculated food consumption rate of 70 g/day, an estimated daily dietary intake of zinc of 69 mg/kg-day was calculated. Further analysis of this study is being undertaken.
Although the Samanta and Pal (1985) study measured reproductive endpoints that could impair a wildlife population's sustainability, the short duration of the study and the lack of a demonstration of a dose-response relationship made it unsuitable for the calculation of a benchmark value. The Bleavins et al. (1983) study focused on the effects of dietary zinc at a single dose and so an adequate dose-response relationship could not be established.

Because no additional mammalian toxicity data were identified, the Schlicker and Cox (1968) study used to calculate a freshwater mammalian benchmark was also used for the terrestrial ecosystem.

Birds: Study done by Stahl et al (1990) (as cited by Sample et al., 1996) were used to derive CSCLs for birds. They examined zinc's effects on the reproduction of white-leghorn hens by feeding hens at 20, 200, and 2000 ppm with 28 ppm zinc in all basal diet. Hens treated with 2028 ppm (2000 + 28 ppm basal diet) exhibited decrease in egg hatchability. Based on these results, a NOAEL of 228 and a LOAEL of 2028 can be inferred for reproductive effects. Since information on food intake was not clear from Sample et al. (1996), conversion of the dietary does from body weight required the use of an allometric equation for birds (Nagy, 1987):

$$Food\ consumption\ (kg/day) = 0.0582(W^{0.651})$$

where W is body weight in kilograms. Using a starting weight of 1.935 kg and using the calculated food consumption rate of 0.089 kg/day, the NOAEL of 228 ppm was converted to 11 mg/kg-day and the LOAEL of 2028 mg/kg was converted to 94 mg/kg-day. Additional avian toxicity data were not identified for birds representing the terrestrial ecosystem. Therefore, the study used for freshwater ecosystem was also used to calculate terrestrial avian CSCLs values.

Freshwater Community: Two sources were evaluated in selecting CSCLs for the protection of aquatic biota: (1) Final Chronic Values (FCV) derived under the Great Lakes Water Quality Initiative (GLWQI) (U.S. EPA, 1995b) and (2) National Ambient Water Quality Criteria (NAWQC) published by the EPA Office of Water. The FCV of 1.2E-01 mg/L for zinc and developed under the GLWQI was selected as the appropriate criteria to use in this analysis. The GLWQI value was considered preferable to the NAWQC because: (1) the GLWQI value is based on the same methodology used to develop NAWQC (i.e., Stephan et al., 1985); (2) the NAWQC data set was augmented with previously unavailable acute and chronic toxicity data; and (3) species taxa used to generate the GLWQI values are suitable for national application since they include species and taxa found throughout the United States. It should be noted that the toxicity of zinc is hardness dependent; therefore, the FCV (in µg/L) was calculated using the following equation (US EPA, 1995a), assuming a water hardness of 100 mg/L as calcium carbonate ($CaCO_3$):

$$e^{0.8473(\ln \text{hardness}) + 0.884}$$

Although total concentrations of metals are still deemed scientifically defensible by the Agency, recent Agency guidance recommends the use of dissolved metal concentrations to better reflect the bioavailability of metals (e.g., Prothro, 1993). Consequently, the FCV for zinc was adjusted to provide dissolved concentrations as described in 60 FR22231 (*Water Quality Standards...Revision of Metals Criteria*). The zinc FCV was adjusted using a conversion factor (CF) of 0.986 for chronic effects to give a dissolved surface water CSCL of 1.2E-01 mg/L. This adjustment reflects the current Agency position on criteria development and regulatory application of metals; however, the issue of metal bioavailability in surface waters is the topic of intensive research (e.g., Bergman and Dorward-King, eds, 1997). For example, the relationship between water characteristics (e.g., dissolved organic matter), copper bioavailability, and toxicity has been investigated in some detail (e.g., Allen and Hansen, 1996). For completeness, the total and dissolved surface water CSCLs are presented in Table 1 even though the values are identical.

Amphibians: No suitable subchronic or chronic studies were identified which studied the effects of zinc toxicity on reproductive or developmental endpoints in amphibian species. The variability between experimental designs and test endpoints made consistent comparisons between chronic data prohibitive; however, both acute and chronic data were identified to characterize the toxicity of zinc to amphibian species. Review of data collected from twenty-five experiments indicate that the acute toxicity of zinc ranges from 0.01 to 155 mg/L, with a geometric mean of 6.5 mg/L. Acute studies were conducted on various amphibian species (i.e., ten amphibian species represented) during embryo, tadpole, and adult lifestages. The observation that the lowest acute amphibian value (i.e., 0.01 mg zinc/L) is one order of magnitude less than the FAV, of 0.12 mg zinc/L determined for the freshwater community indicates that some amphibian species may be equally or more sensitive than other freshwater receptors. During 61 day exposures no effects in metamorphosis were noted at 0.1 mg zinc/L while no effects to survival were indicated at 0.4 mg zinc/L during 4-day exposures. However, a LOEC level of 0.8 mg zinc/L was suggested during 96 hours exposures to *Xenopus laevis*. Given the lack of comparable chronic amphibian data (i.e., variable endpoints and duration), a CSCL of 6.5 mg zinc/L was derived based on acute toxicity. Since the CSCL is based on acute data (i.e., lethality), the severity of the potential adverse effects that this CSCL indicates should be noted. Investigations are ongoing to review the possibility of incorporating amphibian data into the NAWQC. Since amphibian species are more likely to breed in standing waters such as wetlands or ponds, the appropriateness of combining protective levels of amphibian receptors and the freshwater community is unclear at this time (Power et al., 1989; U.S. EPA, 1996).

Algae and Aquatic Plants: Relevant endpoints for aquatic plants focused on the ability of plants to support higher trophic levels as well as the ability to provide habitat for other species in the freshwater ecosystem. The benchmarks for aquatic plants were either: (1) a no observed effects concentration (NOEC) or a lowest observed effects concentration (LOEC) for vascular aquatic plants (e.g., duckweed) or (2) an effective concentration (EC_{xx}) for a species of freshwater algae, frequently a species of green algae (e.g., *Selenastrum* *capricornutum*). The aquatic plant benchmark for zinc is 3.0E-02 mg/L based on the incipient inhibition of growth in *Selenastrum capricornutum* (Suter and Tsao, 1996). Low confidence is placed in this CSCL since it is only based on one study.

Benthic Community- The premier source of field sediment data is the NOAA, which annually collects and analyzes sediment samples from sites located in coastal marine and estuarine environments throughout the United States as part of the National Status and Trends Program (NSTP). From the range of adverse effects data, CSCLs are developed estimating the 10th percentile effects concentration (ER-L) and a median effects concentration (ER-M) for adverse effects in the sediment community (Long et al., 1995). These values are not NOAA standards; rather, they are used to rank sites based on the potential for adverse ecological effects. A second criteria document evaluated for sediment criteria development was the *Approach to the Assessment of Sediment Quality in Florida Coastal Waters Volume 1- Development and Evaluation of Sediment Quality Assessment Guidelines)* (MacDonald et al., 1994) published by the Florida Department of Environmental Protection (FDEP). The criteria developed by FDEP were also based on the NOAA data; however, the method of derivation of the criteria was changed. FDEP calculated the criteria (i.e., threshold effects level, TEL) from the geometric mean of the 50^{th} percentile of no effects data and the 15^{th} percentile of the low effects data. The NOAA data, used in both documents, is based on total metal concentrations in sediments, and the toxicity endpoints were measured on species of amphipods, arthropods, and bivalves in addition to a variety of community-based endpoints (e.g., abundance, mortality, species composition, species richness). The FDEP criterion was chosen above the NOAA criterion for the following reasons; (1) the same database was used for both the NOAA criteria and the FDEP criteria development only different derivation methods were used; (2) in most cases, the FDEP criterion was more conservative than the NOAA criteria because a larger portion of the low effects data was used in benchmark development; (3) the marine TEL developed by the FDEP were found to be analogous to TELs observed in freshwater organisms (Smith et al., 1995).

The CSCL for zinc was derived from 411 toxicity data points for low and no effects levels. For the screening level analysis of zinc, the TEL of 1.2E+02 mg zinc/kg sediment was selected as an appropriate sediment CSCL. Based on the quality and quantity of zinc sediment data, the degree of confidence in the TEL value for zinc was considered high (MacDonald, 1994).

Terrestrial Plants: As presented in Efroymson et al. (1997a), phytotoxicity benchmarks were selected by rank ordering the lowest observable effects concentration (LOEC) values and then approximating the 10th percentile. If fewer than 10 studies were available, the lowest LOEC was selected as the benchmark. Such LOECs applied to reductions in plant growth, yield, or seed elongation, or other effects reasonably assumed to impair the ability of a plant population to sustain itself. The selected benchmark for phytotoxic effects of zinc in soils is 50 mg/kg (Efroymson et al., 1997a). The derivation of the CSCL is based on 14 phytotoxicity data points on various agricultural (e.g., barley, ryegrass) species measuring growth endpoints such as height and weight of shoots and roots and germination success. Considering this CSCL was based on multiple studies over a range of species, confidence in this benchmark is high.

Soil Community: Although a community-based CSCL is available from Hazardous Waste Identification Rule (RTI, 1995a), the value therein is below the average background concentration of 40 to 55 mg zinc/kg soil. Therefore, it is proposed that the CSCL based on microbial processes of 100 mg zinc/kg soil is used; it is based on 47 reported effects on microbial activities from zinc exposure (Efroymson et al., 1997b). The toxicity endpoints measured in microorganisms included effects such as enzyme activities, nitrogen transformation, and mineralization. These functions have been recognized to play important roles in nutrient cycling, which provides nutrients in available forms to plants. However, as important as those processes are, use of this CSCL may have limited utility. Basing a CSCL on only one species or taxa does not consider the complex processes and interactions characteristic of functional soil communities. Community-based CSCLs should be used as they become available. Confidence in this CSCL is low.

Table 1. Zinc CSCLs in Soil, Sediment, Surface Water, and Plant Tissue Developed for Each Representative Receptor

Receptor	CSCL	Units	Exposure Pathway	Representative Species	Reference
Aquatic					
Mammals	9.3E+01	mg/L water	Food web	River otter	Schlicker and Cox, 1968
Birds	8.6E+00	mg/L water	Food web	Kingfisher	Sample et al., 1996
Algae and Aquatic Plants	3.0E-02	mg/L water	Direct contact	*Selenastrum capricornutum*	Suter and Tsao, 1996
Freshwater Community					
Total	1.2E-01	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1995b
Dissolved	1.2E-01	mg/L water	Direct contact	Aquatic biota	U.S. EPA, 1995b; 60FR 22229
Benthic Community	1.2E+02	mg/kg sediment	Direct contact	Benthos	MacDonald, 1994
Amphibians (acute effects)	6.5E+00	mg/L water	Direct contact	Various amphibian species	Power et al., 1989; U.S. EPA, 1996
Terrestrial					
Mammals	1.8E+04	mg/kg soil	Food web	Raccoon	Schlicker and Cox, 1968
Birds	2.8E+02	mg/kg soil	Food web	American woodcock	Sample et al., 1996
Mammals	9.3E+02	mg/kg plant tissue	Food web	Meadow vole	Schlicker and Cox, 1968
Birds	2.8E+02	mg/kg plant tissue	Food web	Northern bobwhite	Sample et al., 1996
Plant Community	5.0E+01	mg/kg soil	Direct contact	Plants (various species)	Efroymson et al., 1997a
Soil Community	1.0E+01	mg/kg soil	Direct contact	Soil microorganisms	Efroymson et al., 1997b

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Appendix J. Review and Comparison of Available Criteria for Chemical Stressor Concentration Limit (CSCL) Development

DESCRIPTION OF APPENDIX J TABLES FOR FOSSIL FUEL COMBUSTION 2 HIGH-END AND CENTRAL TENDENCY ECOLOGICAL RISK ASSESSMENT

Table 1

Table 1 shows ecotoxicological criteria for sediment biota developed by specific state and federal programs. The programs are listed across each column and each has the reference number (ref) referring to the primary literature. And the basis column indicates the type of methods used to derive criteria. Among the programs, the National Oceanic and Atmospheric Administration (NOAA) has established a set of screening values for sediment biota, the ER-L (Effects Range-Low) (Long et al., 1995). ER-L is the lower 10th percentile concentration of the no effects data set. The Florida Department of the Environment (FL DEP) has a more conservative approach for establishing screening values, TEL (Threshold Effects Level) (MacDonald, 1994). Using the same data set and similar methods of derivation for ER-Ls, TEL is the geometric mean of the 50th percentile concentration of the no effects data set and the 15th percentile concentration of adverse effects. Additionally, TELs are supported by EPA Office of Solid Waste and Emergency Response (OSWER) Superfund program and EPA Region IV Superfund guidance (EPA, 1995b; EPA Region IV, 1995). However, when the TEL is lower than the contract laboratory's quantitation limit, Region IV would use the quantitation limit as the criteria. Oak Ridge National Laboratory (ORNL) considers all the criteria developed by each program (presented here) are suitable for screening assessment purposes; and the lowest criteria among all agencies have usually been chosen as their criteria. This approach concurs with methods used in this analysis. However, to protect all ecological receptors, the criteria for sediment are taken as the lowest criteria from community-based concentrations versus a no effects level concentration for sediment associated wildlife (e.g. concentration corresponding to no adverse effects level for spotted sandpiper as presented in Table 4.2).

Table 2 Series

Table 2.1 shows different ecotoxicological criteria for soil and plants supported by government agencies and programs. Similar to Table 1, the programs are listed across, with each reference numbers (ref) referring to the primary (or secondary) literature. And the basis column indicates the type of methods used to derive criteria. For soil criteria, values from the Canadian Council of Ministers of the Environment (CCME) are based on the threshold effect concentrations protecting soil invertebrates, vascular plants, as well as the exposure effects on mammals and birds (CCME, 1997). Oak Ridge National Laboratory selects the soil concentration affecting earthworm (cocoon production, hatching rates, and juvenile survival) and microbial processes (C mineralization, N transformation, and enzyme activities) (Will and Suter, 1995). Additionally, OSW Hazardous Waste Combustor Protocol supports many of ORNL's earthworm criteria. Other agencies, such as the Dutch National Institute of Public Health and Environmental Protection developed soil criteria based on the no observed effects level (NOEC) that are designed to protect soil fauna 95% of the time (van den Berg et al., 1993; van Straalen and Denneman, 1989). The 50% confidence level is selected because the other more conservative level (a 95% confidence level) appears to be overly conservative for a "no effects" approach. Hazardous Waste Identification Rule's (HWIR) methodology incorporates the approach of the Dutch and the National Ambient Water Quality Criteria (NAWQC) guidelines. As in the Dutch criteria, the HWIR methodology provides criteria that would protect soil fauna 95% of the time at 50% level of confidence; however, in contrast to the Dutch methodology, the HWIR methodology combines NOEC and LOEC data set to avoid being overly conservative; and similar to NAWQC guidelines, the diversity of test species is considered to provide an appropriate level of extrapolation from the test results. Because the FFC2 is designed to provide protective level of all ecological receptors, the lowest value among all community- and representative species-specific CSCLs are selected. This value will be taken as the soil CSCL for the subsequent risk characterization.

For plants criteria, values from the Oak Ridge National Laboratory serve as the primary source of effects data on plants (Will and Suter, 1995). Adverse effects levels for terrestrial vascular plants were identified for endpoints ranging from percent yield to root length. Data collection efforts were focused on growth (e.g., seed germination, seedling) and yield because (1) a substantial body of data exists on these endpoints and (2) these endpoints are highly relevant to plant population sustainability (Will and Suter, 1994). However, in view of the diversity of soils, plant species, and test procedures, it was not possible to derive a benchmark from a single study to predict effects on generic plant communities. Given the deficiency of phytotoxicity database, the Effects range low (ER-L) approach used in Hazardous Waste Identification Rule (adopted from Will and Suter, 1995) was used for this analysis (EPA, 1995). As the ER-L used for sediment, the ER-L for plants estimates the 10^{th} percentile concentration from a range of LOECs for a minimum of 10 data points. When fewer than 10 studies are available, the lowest LOEC value is chosen. Depending on the number of suitable datasets, either a LOEC or an ER-L is selected to form the set of benchmark value.

Table 2.2 shows the geometric mean, range, and sample size of background concentrations for metals found in the eastern, western, and the conterminous United States (Dragun and Chiasson, 1991). Background concentrations are important to conduct relative comparisons to screening criteria. Metal background concentrations vary widely depending on the type of soil and geographical locations. All soil CSCLs selected for this analysis are above the background concentrations.

Table 3 Series

Table 3.1 shows the metals criteria (in total concentration) adopted by government agencies and programs for surface water. Generally speaking, the methodologies used by these agencies are in agreement because the methodologies and approach in establishing water quality standards are very similar. Final Chronic Values (FCVs) and Secondary Chronic Values (SCVs) represent statistically significant thresholds for aquatic biota. Ambient Water Quality Criteria (AWQC), established by the Office of Water, are calculated in the same manner as the FCVs, except they may have statutory significance. The lowest among these criteria and the no effects level concentration for representative freshwater birds and mammals is the surface water CSCL used for this analysis (Table 3). Additionally, the minimum value will be used to calculate dissolved metals CSCL presented in Table 3.2.

Table 3.2 presents the aquatic criteria for dissolved metal concentrations taking into consideration the binding of metals to organic ligands. Although the total concentrations presented in Table 3.1 are still deemed scientifically defensible by US EPA, the agency recommends the use of dissolved metals concentration to better reflect the bioavailability of metals (Prothro, 1993). In Table 3.2, surface water criteria are presented along with the corresponding EPA Conversion Factor (e.g., 60CFR22229-22237). The dissolved criteria are calculated by multiplying the total concentration CSCL by EPA Conversion Factor to arrive at dissolved concentrations for surface water quality CSCLs. The relationship used is as follows:

$$\text{Surface Water CSCL}_{\text{dissolved}} = (\text{Surface Water CSCL}_{\text{total}}) \times (\text{EPA Conversion Factor})$$

where Surface Water Criterion $_{\text{total}}$ is either an AWQC, FCV, or SCV and the EPA Conversion Factor is the fraction of dissolved metal.

Table 4 Series

Table 4.1 shows avian and mammalian benchmark values (mg/kg-day) from three sources: (1) the benchmark derivation derived for this task using the proposed HWIR methodologies (EPA, 1995a); (2) screening benchmark values for hazardous waste sites from Oak Ridge National Laboratory(Sample et al., 1996); and (3) screening level benchmark for hazardous waste combustion facilities (EPA, 1997). Both HWIR and ORNL use NOAEL- and LOAEL-based benchmarks. The hazardous waste combustion facilities protocol presents a NOAEL-based benchmark value (referred as toxicity reference value, TRV) when it is available; otherwise, it uses an uncertainty factor on a LOAEL-based value (or other test endpoints such as LD_{50}) to obtain benchmark values (EPA, 1997). Although the studies chosen for mammalian and avian benchmark development are not always the same for those three major agency programs, the benchmark values extrapolated for each wildlife species are often within an order of magnitude. The benchmark values calculated using the proposed HWIR methodology are used in Table 4.2 and Table 4.3 to derive the no effects and lowest effects level concentrations for representative mammals and birds in freshwater and terrestrial ecosystems, respectively.

Table 4.2 shows the concentrations corresponding to no adverse effects level and lowest adverse effects level for mammals and birds typical of freshwater ecosystem. These concentrations are listed under No Effects and Low Effects columns for each ecological receptor. The concentrations that corresponds to a no observed adverse effects level will be used together with surface water CSCLs (Table 3.1) for determining the lowest CSCL. The selected CSCL will be used for the FFC2 analysis (Table 5.1).

Table 4.3 shows the concentrations corresponding to no adverse effects level and lowest adverse effects level for terrestrial wildlife. These concentrations are listed under No Effects and Low Effects columns for each ecological receptor. The concentrations that corresponds to a no observed adverse effects level will be used together with soil criteria (Table 2.1) for the lowest criteria selection. The selected CSCL will be used for the FFC2 analysis (Table 5.1).

Table 5

Table 5.1 shows the lowest ecotoxicological CSCLs for soil, sediment, and surface water (with acute amphibian CSCLs presented separately from the freshwater community).

- The soil CSCLs are selected from two major sources; one is the concentration that represents no effects level for terrestrial wildlife (Table 4.3); and the other is the CSCL taken from experimental studies on the soil community (earthworm and microfauna) (Table 2.1). Each criteria was compared to background concentrations across the conterminous United States to confirm that CSCLs were above background concentrations. In some cases, sufficient data were not available to support a proposed CSCL (e.g., one microbial endpoint measured in soil). In these specific instances, the next to lowest soil CSCL with more supporting data was selected.

- The sediment CSCL, representing the lowest among all CSCLs was selected from either TELs from Florida, ER-Ls from NOAA, or the no adverse effects concentration for sediment associated wildlife; in this case, the spotted sandpiper.

- For surface water, the CSCL was selected from either the lowest water quality CSCL (Table 3.1) (i.e., freshwater community, algae and aquatic plants, and amphibian CSCLs) and the no effects concentrations for representative freshwater wildlife (Table 4.2). The ecological receptor column shows the corresponding ecological community and species representing the lowest criteria identified for a particular constituent.

Table 6 Series

These tables present the predicted concentration of metals in soil, surface water, and sediments using the high-end and central tendency use scenarios for waste management practices under consideration. Constituent lists vary between different management practices because constituents not presenting risk in the previous iteration of the FFC analysis (i.e., bounding analysis) will not indicate risk in the HE-CT analysis. Therefore, under some management practices constituents were dropped.

Table 7 Series

These tables show the ratios, or hazard quotients, of the modeled concentrations (Table 6) and the ecotoxicological CSCLs for sediment, soil, and surface water (Table 5) using the high-end and central tendency use scenarios for waste management practices under consideration.

Table 8 Series

These tables indicate the measured concentrations in surface impoundment waters of coal ash co-managed sites. Concentrations at the 95th percentile (**Table 8.1**) and the median (**Table 8.2**) are used to determine the potential risk to receptors than may be exposed to surface impoundment water directly (i.e., aquatic community, mammals, birds, and amphibians).

Table 9 Series

These tables present the hazard quotients calculated for receptors of concern from the data presented in Table 8. Hazard quotients calculated for the 95th percentile (**Table 9.1**) and the median (**Table 9.2**) are presented.

Table 10

Table 10 contains the equations used to calculate food consumption rates for both laboratory and wildlife species.

Table 11 Series

These tables include the chemical-specific variables used to calculate food chain exposures to mammals and birds of the freshwater ecosystem. Life history data on the representative receptors consists of body weights, water intake rates, food intake rates, and dietary preferences **(Table 11.1**). In addition, to estimate food chain exposures, a measure of the potential for bioaccumlation is required. For this, constituent-specific bioaccumulation and bioconcentration factors for receptors of the freshwater community are included (i.e., trophic level 2 invertebrates, trophic level 3 fish, trophic level 4 fish) (**Table 11.2**).

Table 12 Series

These tables include the chemical-specific variables used to calculate food chain exposures to mammals and birds of the terrestrial ecosystem. Life history data on the representative receptors consists of body weights, water intake rates, food intake rates, and dietary preferences (**Table 12.1**). To estimate food chain exposures, a measure of the potential for bioaccumlation is required. For this, constituent-specific bioaccumulation and bioconcentration factors for receptors of the terrestrial community are included (i.e., soil biota, plants, and small mammals) (**Table 12.2**).

References

Key to the Tables

Basis for Ecotoxicological Criteria
AET = Apparent Effects Threshold is defined as concentration above which adverse effects occur; for soil, it is also known as Ecotoxicological Interventio (van den Berg, 1993).
AWQC = Ambient Water Quality Criteria, established by the Office of Water, represent statistically significant threshold for aquatic biota.
CCC = Criterion Continuous Concentration is defined as the statistical threshold of unacceptable effect (Stephan, 1985).
CLP PQL = Contract Laboratory Program's Practical Quantitation Limit, developed by EPA Region 4 (EPA, 1996)
ER-L = Effects Range Low defined as the lower 10th percentile concentration estimated to correspond with adverse effects (Long et al., 1995).
ER-L, e = Criteria were derived by selecting the concentration that approximates the 10th percentile of the lowest observed effect values on earthworms (Will & Suter, 1994).
ER-L, m = Criteria were derived by selecting the concentration that approximates the 10th percentile of the lowest observed effect values to microfauna (Will & Suter, 1994).
FCV = Final Chronic Value represents a statistically significant chronic effects threshold for aquatic biota (EPA, 1986).
$HC_{95,50}$ = Concentration for which 95% of species would be protected from adverse effects, at a 50% confidence level (EPA, 1995).
LEL = Lowest Effects Level defined as the 5th percentile of the concentration which protects 95% of benthic infauna (EPA, 1997)
LOEC = Lowest Observed Effects Concentration; concentrations are based on the effects of vascular plants, invertebrates, mammals and birds (CCME, 1
LOEC, p = Lowest Observed Effects Concentration; concentration above which toxicity to plants is considered possible (Kabata-Pendias, 1992)
NOAEL = No Observed Adverse Effects Level
no BCF: Receptors for which appropriate bioconcentration factors were not available to derive a CSCL.
no benmrk: Receptors for which appropriate ecotoxicity data were not available to derive a CSCL.
no benmrk/no BCF: Receptors for which neither ecotoxicity data nor bioconcentration factors were available to derive a CSCL.
SCV = Secondary Chronic Value represents statistically significant thresholds for aquatic biota; calculated when not enough data are available to calculate a FCV (Suter and Tsao, 1996).
TEL = Threshold Effects Level; it is the geometric mean of the 15th percentile in the effects data set and the 50th percentile in the no effects data set. (Florida DEP, 1994)
TRV = Toxicity Reference Value is a screening level criteria developed by EPA Region VI.

Key to the Tables

Federal and State Agencies and Programs
Canadian Council = Recommended Canadian Soil Quality Guidelines. 1997. Canadian Council of Ministers of the Environment.
The Dutch National Institute = van den Berg et al., 1993. Risk assessment of contaminated soil: Proposals for adjusted, toxicologically based Dutch soil c criteria. in F. Arendt, G. J. Annokkee, R. Bosman, and W. J. van den Brink (eds.), Contaminated Soil '93, 349-364. Kluwer Academic Pub. the Netherland
EPA Conversion Factor = U.S. EPA 1995. Water quality standards; establishment of numeric criteria for priority toxic pollutants; states compliance revisio of metals criteria. *Federal Register* , 40 CFR Part 131. May 4, 1994. 2229 - 22237.
EPA Great Lakes Initiative = US EPA, 1995. Great Lakes Water Quality Initiative Criteria Documents for the Protection of Aquatic Life in Ambient Water. Office of Water. EPA 820/B-95/004.
Florida Department of the Enviornment = MacDonald, D. D., 1994. Approach to the assessment of sediment quality in Florida coastal waters. Florida Department of Environmental Protection. Tallahassee, FL.
National Oceanic and Atmo. Administration = Long et al., 1995. Incidence of adverse biological effets within ranges of chemical concentrations in marine and estuarine sediments. Enviorn. Manag. 19: 81-97.
Oak Ridge National Laboratory = US DOE (Department of Energy). 1996. Screening Benchmarks for Ecological Risk Assessment. Version 1.6. Oak Ridge National Laboratory, Oak Ridge, TN.
OSWER Ecotox Thresholds = US EPA, 1996. Eco Update. vol. 3, No. 2. Office of Emergency and Remedial Response. EPA 540/F-95/038.
US EPA Region IV = Supplemental Guidance to RAGS: Region 4 Bulletins. Ecological Risk Assessment. Waste Management Division. October 1996.
US EPA Office of Water = Ambient Water Quality Criteria Documents.
OSW HWIR methodology = EPA, 1995. Technical support document for the hazardous waste identification rule: Risk assessment for human and ecologic receptors. (vol. 1 and 2). Prepared for US EPA Office of Solid Waste by Research Triangle Institute, RTP, NC.
OSW Screening Levels = US EPA, 1997. Protocol for Screening Level Ecological Risk Assessment at Hazardous Waste Combustion Facilities. (vol. 1 and 2). Office of Solid Waste. February 28. Internal Review Draft. EPA-R6-096-003.

Table 1.1 Ecotoxicological Criteria for Sediment Identified in State and Federal Programs (mg/kg sediment)

Constituent	Oak Ridge National Laboratory			Florida Department of the Environment			National Oceanic and Atmo. Admin			OSW Screening Levels			OSWER Ecotox Thresholds			US EPA Region IV		
	value	basis	ref	value	basis	ref	value	basis	ref	value	basis	ref	value	basis	ref	value	basis	ref
Aluminum	--			--			--			2.70E+04		9	--			--		
Antimony	2.0E+00	ER-L	6	--			2.0E+00	ER-L	6	2.00E+00	ER-L	6	--			1.2E+01	CLP PQL	12
Arsenic	7.2E+00	TEL	1	7.2E+00	TEL	1	8.2E+00	ER-L	7	6.00E+00	LEL	8	8.2E+00	ER-L	7	7.2E+00	TEL	1
Barium	--			--			--			--			--			--		
Beryllium	--			--			--			3.70E-02		9	--			--		
Boron	--			--			--			--			--			--		
Cadmium	6.8E-01	TEL	1	6.8E-01	TEL	1	1.2E+00	ER-L	7	1.20E+00	ER-L	7	1.2E+00	ER-L	7	1.0E+00	CLP PQL	12
Chromium	5.2E+01	TEL	1	5.2E+01	TEL	1	8.1E+01	ER-L	7	8.1E+00	ER-L	7	8.1E+01	ER-L	7	5.2E+01	TEL	1
Cobalt	--			--			--			--			--			--		
Copper	1.9E+01	TEL	1	1.9E+01	TEL	1	3.4E+01	ER-L	7	3.4E+00	ER-L	9	3.4E+01	ER-L	7	1.9E+01	TEL	1
Lead	3.0E+01	TEL	1	3.0E+01	TEL	1	4.7E+01	ER-L	7	4.67E+01	ER-L	7	4.7E+01	ER-L	7	3.0E+01	TEL	1
Mercury	1.3E-01	TEL	1	1.3E-01	TEL	1	1.5E-01	ER-L	7	1.50E-01	ER-L	7	1.5E-01	ER-L	7	1.3E-01	TEL	1
Molybdenum	--			--			--			--			--			--		
Nickel	1.6E+01	TEL	1	1.6E+01	TEL	1	2.1E+01	ER-L	7	2.09E+01	ER-L	7	2.1E+01	ER-L	7	1.6E+01	TEL	1
Selenium	--			--			--			1.00E-01	AET	9	--			--		
Silver	7.3E-01	TEL	1	7.3E-01	TEL	1	1.0E+00	ER-L	7	1.00E+00	ER-L	7	--			2.0E+00	CLP PQL	12
Thallium	--			--			--			1.6E+00		9	--			--		
Vanadium	--			--			--			--			--			--		
Zinc	1.2E+02	TEL	1	1.2E+02	TEL	1	1.5E+02	ER-L	7	1.50E+02	ER-L	7	1.5E+02	ER-L	7	1.2E+02	TEL	1

Note: Ecotoxicological criteria for sediment biota were not developed under the proposed HWIR methodology.

Table 2.1 Ecotoxicological Criteria for the Soil Biota and Plants Identified in State and Federal Programs (mg/kg soil)

	---Criteria for Soil Biota---															---Criteria for Plants---					
Constituent	Canadian Council			Oak Ridge National Laboratory			OSW HWIR Methodology			OSW Screening Levels			The Dutch National Instit.			OSW HWIR Methodology			Oak Ridge National Laboratory		
	value	basis	ref	value	basis	ref	value	basis	ref	value	basis	ref	value	basis	ref	value	basis	ref	value	basis	ref
Aluminum	--			6.0E+02	ER-L, m	11	--			--			--			--			5.0E+01	LOEC	19
Antimony	--			--			--			--			--			5.0E+00	LOEC	19	5.0E+00	LOEC	19
Arsenic	1.2E+01	LOEC	10	1.0E+02	ER-L, m	11	--			6.0E+01	ER-L, e	11	4.0E+01	AET	15	1.0E+01	ER-L	19	1.0E+01	ER-L	19
	--			6.0E+01	ER-L, e	11	--			--			--								
Barium	--			3.0E+03	ER-L, m	11	--			--			6.3E+02	AET	15	5.0E+02	LOEC	19	5.0E+02	LOEC	19
Beryllium	--			--						--			--			1.0E+01	ER-L	19	1.0E+01	ER-L	19
Boron	--			2.0E+01	ER-L, m	11	--			--			--			--			5.0E-01	LOEC	19
Cadmium	1.4E+00	LOEC	10	2.0E+01	ER-L, e	11	1.0E+00	$HC_{95,50}$	13	2.0E+01	ER-L, e	11	1.2E+01	AET	15	3.0E+00	ER-L	19	3.0E+00	ER-L	19
				2.0E+01	ER-L, m	11															
Chromium	6.4E+01	LOEC	10	4.0E-01	ER-L, e	11	--			1.0E-01	NOAEL	9	2.3E+02	AET	15	1.0E+00	LOEC	19	1.0E+00	LOEC	19
	--			1.0E+01	ER-L, m	11	--			--			--								
Cobalt	--			1.0E+03	ER-L, m	11	--			--			2.4E+02	AET	15	--			2.0E+01	LOEC	19
Copper	6.3E+01	LOEC	10	5.0E+01	ER-L, e	11	2.1E+01	$HC_{95,50}$	13	5.0E+01	ER-L, e	11	1.9E+02	AET	15	1.0E+02	LOEC	19	1.0E+02	LOEC	19
	--			1.0E+02	ER-L, m	11	--			--			--								
Lead	7.0E+01	LOEC	10	5.0E+02	ER-L, e	11	2.8E+01	$HC_{95,50}$	13	5.0E+01	NOAEL	9	2.9E+02	AET	15	5.0E+01	ER-L	19	5.0E+01	ER-L	19
	--			9.0E+02	ER-L, m	11	--			--			--								
Mercury	6.6E+00	LOEC	10	1.0E-01	ER-L, e	11	--			7.9E-03	LD50/100	9	1.0E+01	AET	15	3.0E-01	LOEC	19	3.0E-01	LOEC	19
	--			3.0E+01	ER-L, m	11	--			--			--								
Molybdenum	--			2.0E+02	ER-L, m	11	--			--			--			2.0E+00	LOEC	19	2.0E+00	LOEC	19
Nickel	--			9.0E+01	ER-L, m	11	--			2.0E+02	ER-L, e	11	2.1E+02	AET	15	3.0E+01	LOEC	19	3.0E+01	LOEC	19
				2.0E+02	ER-L, e	11															
Selenium	--			7.0E+01	ER-L, e	11	--			7.0E+01	ER-L, e	11	--			1.0E+00	LOEC	19	1.0E+00	LOEC	19
				1.0E+02	ER-L, m	11	--			--			--								
Silver	--			5.0E+01	ER-L, m	11	--			--			--			2.0E+00	LOEC	19	2.0E+00	LOEC	19
Thallium	--			--			--			--			--			--			1.0E+00	LOEC	19
Vanadium	1.3E+02	LOEC	10	2.0E+01	ER-L, m	11	--			--			--			2.0E+00	LOEC	19	2.0E+00	LOEC	19
Zinc	2.0E+02	LOEC	10	2.0E+02	ER-L, e	11	2.3E+01	$HC_{95,50}$	13	6.6E+00	LC50/100	9	7.2E+02	AET	15	5.0E+01	ER-L	19	5.0E+01	ER-L	19
				1.0E+02	ER-L, m	11															

Table 2.2 Background Concentrations of Metals Found in the US (mg/kg soil)

Constituent	Background Concentration by Region								
	Conterminous US			Eastern US			Western US		
	Geo. mean	Range	Sample Size	Geo. mean	Range	Sample Size	Geo. mean	Range	Sample Size
Aluminum	47,000	700 - >100,000	1247	33,000	7000 - >100,000	477	58,000	5000 - >100,000	770
Antimony	0.48	<1.0 - 8.8	354	0.52	<1.0 - 8.8	131	0.47	<1.0 - 2.6	223
Arsenic	5.2	<1.0 - 97	1257	4.8	<1.0 - 73	527	5.5	<1.0 - 97	730
Barium	440	10 - 5000	1319	290	10 - 1500	541	580	70 - 5000	778
Beryllium	0.63	<1.0 - 15	1303	0.55	<1.0 - 70	525	0.68	<1.0 - 15	778
Boron	26	<20 - 300	1319	31	<20 - 150	541	23	<20 - 300	778
Cadmium	--	--	--	--	--	--	4.3 +	1.0 - 10	12
Chromium	37	1.0 - 2000	1319	33	1.0 - 1000	541	41	3.0 - 2000	778
Cobalt	6.7	<3.0 - 70	1311	5.9	<3.0 - 70	533	7.1	<3.0 - 50	778
Copper	17	<1.0 - 700	1311	13	<1.0 - 700	533	21	2.0 - 300	778
Lead	16	<10 - 700	1319	14	<10 - 300	541	17	<10 - 700	778
Mercury	0.058	<0.01 - 4.6	1267	0.081	<0.01 - 3.4	534	0.046	<0.01 - 4.6	733
Molybdenum	0.59	<3.0 - 15	1298	0.32	<3.0 - 15	524	0.85	<3.0 - 7.0	774
Nickel	13	<5.0 - 700	1318	11	<5.0 - 700	540	15	<5.0 - 700	778
Selenium	0.26	<0.1 - 4.3	1267	0.3	<0.1 - 3.9	534	0.23	<0.1 - 4.3	733
Silver	--	--	--	0.14*	<0.22 - 0.49	136	<0.5	0.5 - 1.5	168
Thallium	2.23 ++	<0.25 - 10	34	--	--	--	--	--	--
Vanadium	58	7.0 - 500	1319	43	<7.0 - 300	541	70	7.0 - 500	778
Zinc	48	<5.0 - 2900	1248	40	50 - 2900	482	55	10 - 2100	1248

Source: Dragun, J. and A. Chiasson. 1991. *Elements in North American Soils* . Hazardous Materials Control Resources Institute. Greenbelt, MD.
Shading indicates arithmetic mean

++ data from Michigan
* data from Northern Great Planes
\+ data from Southeastern US

Table 3.1 Ecotoxicological Criteria for Surface Water Identified in State and Federal Agencies (mg/L)

Constituent	EPA Office of Water			Oak Ridge National Laboratory			EPA Great Lakes Initiative			OSW HWIR Methodology		
	value	basis	ref	value	basis	ref	value	basis	ref	value	basis	ref
Aluminum	8.70E-02	AWQC	23	8.70E-02	AWQC	23	--			--		
Antimony	3.0E-02	draft FCV	20	3.0E-02	draft FCV	20	--			3.0E-02	draft FCV	20
Arsenic $_{total}$	--			--			--			--		
Arsenic III	1.9E-01	AWQC	18	1.9E-01	AWQC	18	1.5E-01	FCV	4	1.9E-01	AWQC	18
Arsenic V	--			8.1E-03	SCV	11	--			8.1E-03	SCV	14
Barium	--			4.0E-03	SCV	11	--			1.0E+00	SCV	13
Beryllium	--			6.6E-04	SCV	11	--			5.1E-03	SCV	14
Boron	--			1.6E-03	SCV	11	--			--		
Cadmium	***1.1E-03***	AWQC	18	***1.1E-03***	AWQC	18	***2.5E-03***	FCV	4	***1.1E-03***	AWQC	18
Chromium $_{total}$	--			--			--			--		
Chromium III	***2.1E-01***	AWQC	18	***2.1E-01***	AWQC	18	***8.6E-02***	FCV	4	***2.1E-01***	AWQC	18
Chromium VI	1.1E-02	AWQC	18	1.1E-02	AWQC	18	1.1E-02	FCV	4	1.1E-02	AWQC	18
Cobalt	--			2.3E-02	SCV	11	--			--		
Copper	***1.2E-02***	AWQC	18	***1.2E-02***	AWQC	18	***9.3E-03***	FCV	4	***1.2E-02***	AWQC	18
Lead	***3.2E-03***	AWQC	18	***3.2E-03***	AWQC	18	--			***3.2E-03***	AWQC	18
Mercury	1.2E-05	AWQC	18	1.3E-03	FCV	18	9.1E-04	FCV	4	1.3E-03	FCV	18
Methyl Mercury	--			2.8E-06	SCV	11	--			--		
Molybdenum	--			3.7E-01	SCV	11	--			2.4E-01	SCV	14
Nickel	***1.6E-01***	AWQC	18	***1.6E-01***	AWQC	18	***5.2E-02***	FCV	4	***1.6E-01***	AWQC	18
Selenium $_{total}$	5.0E-03	AWQC	21	5.0E-03	AWQC	18	5.0E-03	FCV	4	5.0E-03	AWQC	18
Selenium IV	2.8E-02	FCV	21	--			2.8E-02	CCC	4	--		
Selenium VI	9.7E-03	FCV	21	--			9.5E-03	FCV	4	--		
Silver	--			3.6E-04	SCV	11	--			3.6E-04	SCV	14
Thallium	--			1.2E-02	SCV	11	--			--		
Vanadium	--			2.0E-02	SCV	11	--			--		
Zinc	***1.1E-01***	AWQC	18	***1.1E-01***	AWQC	18	***1.2E-01***	FCV	4	***1.1E-01***	AWQC	18

Values in italicized bold indicate hardness dependent criterion normalized to 100 mg/L CaCO3

Table 3.1 Ecotoxicological Criteria for Surface Water Identified in State and Federal Agencies (mg/L)

Constituent	OSW Screening Level			OSWER Ecotox Thresholds			US EPA Region IV		
	value	basis	ref	value	basis	ref	value	basis	ref
Aluminum	1.50E-04	subchronic LD50	9	--			8.7E-02	AWQC	12
Antimony	3.00E-03	draft FCV	9	--			1.6E-01	SCV	12
Arsenic $_{total}$	--			--			--		
Arsenic III	1.90E-01	AWQC	9	1.9E-01	AWQC	18	1.9E-01	AWQC	18
Arsenic V	--			8.1E-03	SCV	14	--		
Barium	2.60E-01	EC_{50} / 100	9	3.9E-03	SCV	14	--		
Beryllium	5.30E-04	Chronic LOAEL	9	5.1E-03	SCV	14	5.3E-04	SCV	12
Boron	--			--			7.5E-01	AWQC	12
Cadmium	1.10E-03	AWQC	9	***1.0E-03***	AWQC	18	***1.0E-03***	AWQC	18
Chromium $_{total}$	--			--			--		
Chromium III	--			***2.0E-01***	AWQC	18	***2.0E-01***	AWQC	18
Chromium VI	1.10E-02	AWQC	9	1.0E-02	AWQC	18	1.0E-02	AWQC	18
Cobalt	--			3.0E-03	SCV	14	--		
Copper	1.20E-02	AWQC	9	***1.1E-02***	AWQC	18	***1.1E-02***	AWQC	18
Lead	3.20E-03	AWQC	9	***2.5E-03***	AWQC	18	***3.2E-03***	AWQC	18
Manganese									
Mercury	1.20E-05	AWQC	9	1.3E-03	FCV	18	1.2E-05	AWQC	18
Methyl Mercury	--			3.0E-06	SCV	14	--		
Molybdenum	--			2.4E-01	SCV	14	--		
Nickel	1.60E-01	AWQC	9	***1.6E-01***	AWQC	18	***1.6E-01***	AWQC	18
Selenium $_{total}$	5.00E-03	AWQC	9	5.0E-03	AWQC	21	5.0E-03	AWQC	21
Selenium IV	--			--			--		
Selenium VI	--			--			--		
Silver	9.2E-04	SCV	9	--			1.2E-05	SCV	12
Thallium	4.0E-03	Chronic LOAEL	9	--			4.0E-03	SCV	12
Vanadium	1.9E-02	SCV	9	1.9E-02	SCV	14	--		
Zinc	1.6E-01	AWQC	9	***1.0E-01***	AWQC	18	***1.0E-01***	AWQC	18

Values in italicized bold indicate hardness dependent criterion normalized to 100 mg/L CaCO3

Table 3.2 Total and Dissolved Ecotoxicological Criteria for Surface Water (mg/L)

Surface Water Criterion $_{dissolved}$ = (Surface Water Criterion $_{total}$) X (Conversion Factor)

Constituent	Surface Water Criterion $_{total}$ total concentration			EPA Conversion Factor	Surface Water Criterion $_{dissolved}$ dissolved concentration
	value	receptor	ref	chronic effects	freshwater only
Aluminum	8.70E-02	Aquatic Biota	23	--	--
Antimony	3.0E-02	Aquatic Biota	18	--	--
Arsenic total	2.9E-02	Kingfisher		--	--
Arsenic III	1.5E-01	Aquatic Biota	4	1.000	1.5.E-01
Arsenic V	8.1E-03	Aquatic Biota	11	1.000	8.1.E-03
Barium	4.0E-03	Aquatic Biota	11	--	--
Beryllium	6.6E-04	Aquatic Biota	11	--	--
Boron	1.6E-03	Aquatic Biota	11	--	--
Cadmium	2.5E-03	Aquatic Biota	4	0.909	2.3E-03
Chromium total	4.1E+00	Kingfisher		--	--
Chromium III	8.6E-02	Aquatic Biota	4	0.860	7.4E-02
Chromium VI	1.1E-02	Aquatic Biota	4	0.962	1.1E-02
Cobalt	2.3E-02	Aquatic Biota	11	--	--
Copper	9.3E-03	Aquatic Biota	4	0.960	8.9E-03
Lead	3.0E-04	River Otter		0.791	2.4E-04
Mercury	1.9E-07	Kingfisher	22	--	--
Methyl Mercury	2.8E-06	Aquatic Biota	4	--	--
Molybdenum	3.7E-01	Aquatic Biota	11	--	--
Nickel	5.2E-02	Aquatic Biota	4	0.997	5.2E-02
Selenium total	2.6E-04	River Otter	4	--	--
Selenium IV	2.8E-02	Aquatic Biota	4	--	--
Selenium VI	9.5E-03	Aquatic Biota	4	--	--
Silver	3.6E-04	Aquatic Biota	11	--	--
Thallium	1.2E-02	Aquatic Biota	11	--	--
Vanadium	2.0E-02	Aquatic Biota	11	--	--
Zinc	1.2E-01	Aquatic Biota	4	0.986	1.2E-01

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference		Oak Ridge National Lab Screening Benchmarks		reference	OSW Screening Level Benchmarks		reference
Aluminum	NOAEL	LOAEL			NOAEL	LOAEL		Endpoint / Dose	TRV	
							Sample et al., 1996			
appropriate studies not identified				Mouse	***1.9E+00***	1.9E+01				
Mink	ID	ID			***1.9E+00***	1.9E+01				
River otter	ID	ID			***1.9E+00***	1.9E+01				
Short-tailed shrew	ID	ID			***1.9E+00***	1.9E+01				
Deer mouse	ID	ID								
Meadow vole	ID	ID			***1.9E+00***	1.9E+01				
Eastern cottontail	ID	ID								
Red fox	ID	ID			***1.9E+00***	1.9E+01				
Raccoon	ID	ID								
White-t deer	ID	ID			***1.9E+00***	1.9E+01				
							Sample et al., 1996			
appropriate studies not identified				Dove	1.1E+02	ID				
Bald eagle	ID	ID								
Osprey	ID	ID			1.1E+02	ID				
Great B. heron	ID	ID			1.1E+02	ID				
Mallard	ID	ID								
Lesser scaup	ID	ID								
Kingfisher	ID	ID			1.1E+02	ID				
Spotted sandpiper	ID	ID								
Herring gull	ID	ID								
Red-tailed hawk	ID	ID			1.1E+02	ID				
Amer. Kestrel	ID	ID								
Northern bobwhite	ID	ID								
Amer. Robin	ID	ID			1.1E+02	ID				
Amer. Woodcock	ID	ID			1.1E+02	ID				

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks			reference
Antimony	NOAEL	LOAEL			NOAEL	LOAEL			Endpoint / Dose	TRV	
			Rossi et al., 1987				Sample et al., 1996				EPA, 1997
Rat	1.4E-01	1.4E+00		Mouse	***1.3E-01***	1.3E+00		Rat	LOAEL / 0.35	3.5E-02	
Mink	1.1E-01	1.1E+00			***5.2E-03***	5.2E-02					
River otter	6.2E-02	6.2E-01			***3.1E-02***	3.1E-01					
Short-tailed shrew	2.8E-01	2.8E+00			***1.5E-01***	1.5E+00					
Deer mouse	2.8E-01	2.8E+00									
Meadow vole	2.3E-01	2.3E+00			***1.1E-01***	1.1E+00					
Eastern cottontail	9.7E-02	9.7E-01									
Red fox	7.2E-02	7.2E-01			***3.6E-02***	3.6E-01					
Raccoon	6.9E-02	6.9E-01									
White-t deer	3.4E-02	3.4E-01			***1.9E-02***	1.9E-01					

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks			reference
Arsenic	NOAEL	LOAEL			NOAEL	LOAEL			Endpoint / Dose	TRV	
			Byron et al., 1967				Sample et al., 1996				EPA, 1997
Rat	4.6E+00	9.3E+00		Mouse	***1.3E-01***	1.3E+00		Dog	LOAEL / 3.1	3.1E-01	
Mink	4.1E+00	8.2E+00			***5.2E-02***	5.2E-01					
River otter	2.3E+00	4.6E+00			***3.1E-02***	3.1E-01					
Short-tailed shrew	1.0E+01	2.1E+01			***1.5E-01***	1.5E+00					
Deer mouse	1.0E+01	2.0E+01									
Meadow vole	8.5E+00	1.7E+01			***1.1E-01***	1.1E+00					
Eastern cottontail	3.6E+00	7.2E+00			***5.0E-02***	5.0E-01					
Red fox	2.7E+00	5.3E+00			***3.6E-02***	3.6E-01					
Raccoon	2.6E+00	5.1E+00									
White-t deer	1.3E+00	2.6E+00			***1.9E-02***	1.9E-01					
			Stanley at al., 1994				Sample et al., 1996				EPA, 1997
Mallard	5.7E-03	2.3E-02		Mallard	5.1E+00	1.3E+01		Mallard	LD50/2.5	2.5E-02	
Bald eagle	2.3E-02	9.4E-02									
Osprey	2.9E-02	1.2E-01			5.1E+00	1.3E+01					
Great B. heron	2.6E-02	1.1E-01			5.1E+00	1.3E+01					
Mallard	3.1E-02	1.3E-01									
Lesser scaup	3.5E-02	1.4E-01									
Kingfisher	5.3E-02	2.1E-01			5.1E+00	1.3E+01					
Spotted sandpiper	7.2E-02	2.9E-01									
Herring gull	3.2E-02	1.3E-01									
Red-tailed hawk	3.2E-02	1.3E-01			5.1E+00	1.3E+01					
Amer. Kestrel	5.5E-02	2.2E-01									
Northern bobwhite	5.0E-02	2.0E-01									
Amer. Robin	6.1E-02	2.4E-01			5.1E+00	1.3E+01					
Amer. Woodcock	5.1E-02	2.0E-01			5.1E+00	1.3E+01					

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks			reference
Barium	NOAEL	LOAEL			NOAEL	LOAEL			Endpoint / Dose	TRV	
							Sample et al., 1996				EPA, 1997
Rat	ID	ID		Rat	5.1E+00	NA		Rat	NOAEL / 0.51	5.1E-01	
Mink	ID	ID			5.1E+00						
River otter	ID	ID									
Short-tailed shrew	ID	ID			5.1E+00						
Deer mouse	ID	ID			5.1E+00						
Meadow vole	ID	ID			5.1E+00						
Eastern cottontail	ID	ID			5.1E+00						
Red fox	ID	ID			5.1E+00						
Raccoon	ID	ID									
White-t deer	ID	ID			5.1E+00						
			Sample et al., 1996				Sample et al., 1996				
Chick	2.1E+01	4.2E+01		Chick	2.1E+01	4.2E+01		Not Available			
Bald eagle	8.9E+00	1.8E+01									
Osprey	1.1E+01	2.2E+01			2.1E+01	4.2E+01					
Great B. heron	1.0E+01	2.0E+01			2.1E+01	4.2E+01					
Mallard	1.2E+01	2.4E+01									
Lesser scaup	1.3E+01	2.7E+01									
Kingfisher	2.0E+01	4.0E+01			2.1E+01	4.2E+01					
Spotted sandpiper	2.7E+01	5.5E+01									
Herring gull	1.2E+01	2.4E+01									
Red-tailed hawk	1.2E+01	2.4E+01			2.1E+01	4.2E+01					
Amer. Kestrel	2.1E+01	4.2E+01									
Northern bobwhite	1.9E+01	3.8E+01									
Amer. Robin	2.3E+01	4.6E+01			2.1E+01	4.2E+01					
Amer. Woodcock	1.9E+01	3.9E+01			2.1E+01	4.2E+01					

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks			reference
Beryllium	NOAEL	LOAEL			NOAEL	LOAEL			Endpoint / Dose	TRV	
							Sample et al., 1996				EPA, 1997
appropriate studies not identified				Rat	6.6E-01	ID		Mouse	LOAEL / 0.95	9.5E-01	
Mink	ID	ID			5.1E-01	ID					
River otter	ID	ID			3.0E-01	ID					
Short-tailed shrew	ID	ID			1.5E+00	ID					
Deer mouse	ID	ID									
Meadow vole	ID	ID			1.1E+00	ID					
Eastern cottontail	ID	ID			4.9E-01	ID					
Red fox	ID	ID			3.5E-01	ID					
Raccoon	ID	ID									
White-t deer	ID	ID			1.9E-01	ID					

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks		reference
Boron	NOAEL	LOAEL			NOAEL	LOAEL		Endpoint / Dose	TRV	
							Sample et al., 1996			
appropriate studies not identified				Rat	2.8E+01	9.4E+01				
Mink	ID	ID			2.2E+01	7.2E+01				
River otter	ID	ID			1.3E+01	4.3E+01				
Short-tailed shrew	ID	ID			6.2E+01	2.1E+02				
Deer mouse	ID	ID								
Meadow vole	ID	ID			4.7E+01	1.6E+02				
Eastern cottontail	ID	ID			2.1E+01	6.9E+01				
Red fox	ID	ID			1.5E+01	4.9E+01				
Raccoon	ID	ID								
White-t deer	ID	ID			7.9E+00	2.6E+01				
							Sample et al., 1996			
appropriate studies not identified				Mallard	2.9E+01	1.0E+02				
Bald eagle	ID	ID								
Osprey	ID	ID			2.9E+01	1.0E+02				
Great B. heron	ID	ID			2.9E+01	1.0E+02				
Mallard	ID	ID			2.9E+01	1.0E+02				
Lesser scaup	ID	ID								
Kingfisher	ID	ID			2.9E+01	1.0E+02				
Spotted sandpiper	ID	ID								
Herring gull	ID	ID								
Red-tailed hawk	ID	ID			2.9E+01	1.0E+02				
Amer. Kestrel	ID	ID								
Northern bobwhite	ID	ID								
Amer. Robin	ID	ID			2.9E+01	1.0E+02				
Amer. Woodcock	ID	ID			2.9E+01	1.0E+02				

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks			reference
Cadmium	NOAEL	LOAEL			NOAEL	LOAEL			Endpoint / Dose	TRV	
			Soutu et al., 1980				Sample et al., 1996				EPA, 1997
Rat	1.0E+00	1.0E+01		Rat	1.0E+00	1.0E+01		Rat	LOAEL / 2.24	2.2E-01	
Mink	7.5E-01	7.5E+00			7.4E-01	7.4E+00					
River otter	4.5E-01	4.5E+00			4.4E-01	4.4E+00					
Short-tailed shrew	2.1E+00	2.1E+01			2.1E+00	2.1E+01					
Deer mouse	2.0E+00	2.0E+01									
Meadow vole	1.8E+00	1.8E+01			1.6E+00	1.6E+01					
Eastern cottontail	7.2E-01	7.2E+00			7.1E-01	7.1E+00					
Red fox	5.2E-01	5.2E+00			5.1E-01	5.1E+00					
Raccoon	4.9E-01	4.9E+00									
White-t deer	2.5E-01	2.5E+00			2.7E-01	2.7E+01					
			White and Finley, 1978				Sample et al., 1996				EPA, 1997
Mallard	1.4E+00	1.4E+01		Mallard	1.5E+00	2.0E+01		Mallard	NOAEL/11.3	######	
Bald eagle	1.1E+00	1.1E+01									
Osprey	1.4E+00	1.4E+01			1.5E+00	2.0E+01					
Great B. heron	1.3E+00	1.3E+01			1.5E+00	2.0E+01					
Mallard	1.5E+00	1.5E+01									
Lesser scaup	1.7E+00	1.7E+01									
Kingfisher	2.6E+00	2.6E+01			1.5E+00	2.0E+01					
Spotted sandpiper	3.5E+00	3.5E+01									
Herring gull	1.6E+00	1.6E+01									
Red-tailed hawk	1.5E+00	1.5E+01			1.5E+00	2.0E+01					
Amer. Kestrel	1.6E+00	1.6E+01									
Northern bobwhite	2.5E+00	2.5E+01									
Amer. Robin	3.0E+00	3.0E+01			1.5E+00	2.0E+01					
Amer. Woodcock	2.5E+00	2.5E+01			1.5E+00	2.0E+01					

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks			reference
Chromium	NOAEL	LOAEL			NOAEL	LOAEL			Endpoint / Dose	TRV	
			Zahid et al., 1990				Sample et al., 1996				EPA, 1997
Mouse	***3.3E+00***	3.3E+01		Rat	3.3E+00	1.3E+01		Rat	NOAEL / 2.4	######	
Mink	***1.2E+00***	1.2E+01			3.3E+00	1.3E+01					
River otter	***7.4E-01***	7.4E+00			3.3E+00	1.3E+01					
Short-tailed shrew	***3.5E+00***	3.5E+01			3.3E+00	1.3E+01					
Deer mouse	***3.4E+00***	3.4E+01									
Meadow vole	***2.8E+00***	2.8E+01			3.3E+00	1.3E+01					
Eastern cottontail	***1.2E+00***	1.2E+01			3.3E+00	1.3E+01					
Red fox	***8.5E-01***	8.5E+00			3.3E+00	1.3E+01					
Raccoon	***8.0E-01***	8.0E+00									
White-t deer	***3.9E-01***	3.9E+00			3.3E+00	1.3E+01					
			Sample et al., 1996				Sample et al., 1996				EPA, 1997
Duck	1.0E+00	5.0E+00		Duck	1.0E+00	5.0E+00		Duck	NOAEL/0.56	5.6E-01	
Bald eagle	7.6E-01	3.8E+00									
Osprey	9.4E-01	4.7E+00			1.0E+00	5.0E+00					
Great B. heron	8.6E-01	4.3E+00			1.0E+00	5.0E+00					
Mallard	1.0E+00	5.1E+00									
Lesser scaup	1.1E+00	5.7E+00									
Kingfisher	1.7E+00	8.5E+00			1.0E+00	5.0E+00					
Spotted sandpiper	2.3E+00	1.2E+01									
Herring gull	1.0E+00	5.2E+00									
Red-tailed hawk	1.0E+00	5.1E+00									
Amer. Kestrel	9.8E-01	4.9E+00			1.0E+00	5.0E+00					
Northern bobwhite	1.6E+00	8.2E+00									
Amer. Robin	2.0E+00	9.9E+00			1.0E+00	5.0E+00					
Amer. Woodcock	1.7E+00	8.3E+00			1.0E+00	5.0E+00					

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks		reference	OSW Screening Level Benchmarks		reference
Cobalt	NOAEL	LOAEL		NOAEL	LOAEL		Endpoint / Dose	TRV	
appropriate studies not identified				not available			not available		
Mink	ID	ID							
River otter	ID	ID							
Short-tailed shrew	ID	ID							
Deer mouse	ID	ID							
Meadow vole	ID	ID							
Eastern cottontail	ID	ID							
Red fox	ID	ID							
Raccoon	ID	ID							
White-t deer	ID	ID							
appropriate studies not identified				not available			not available		
Bald eagle	ID	ID							
Osprey	ID	ID							
Great B. heron	ID	ID							
Mallard	ID	ID							
Lesser scaup	ID	ID							
Kingfisher	ID	ID							
Spotted sandpiper	ID	ID							
Herring gull	ID	ID							
Red-tailed hawk	ID	ID							
Amer. Kestrel	ID	ID							
Northern bobwhite	ID	ID							
Amer. Robin	ID	ID							
Amer. Woodcock	ID	ID							

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks			reference
Copper	NOAEL	LOAEL			NOAEL	LOAEL			Endpoint / Dose	TRV	
			Aulerich et al., 1982				Sample et al., 1996				EPA, 1997
Mink	6.2E+00	8.0E+00		Mink	1.2E+01	1.5E+01		Mink	LOAEL / 3.2	3.2E-01	
Mink	6.3E+00	8.1E+00			1.2E+01	1.5E+01					
River otter	3.5E+00	4.5E+00			7.0E+00	9.2E+00					
Short-tailed shrew	1.6E+01	2.1E+01			3.3E+01	4.4E+01					
Deer mouse	1.6E+01	2.0E+01									
Meadow vole	1.3E+01	1.7E+01			2.6E+01	3.4E+01					
Eastern cottontail	5.5E+00	7.1E+00			2.4E+00	9.7E+00					
Red fox	4.1E+00	5.2E+00			8.0E+00	1.1E+01					
Raccoon	3.9E+00	5.0E+00									
White-t deer	1.9E+00	2.5E+00			4.3E+00	5.6E+00					
			Sample et al., 1996				Sample et al., 1996				EPA, 1997
Chick	4.7E+01	6.2E+01		Chick	4.7E+01	6.2E+01		Chicken	NOAEL/40	######	
Bald eagle	2.9E+01	3.8E+01									
Osprey	3.6E+01	4.7E+01			4.7E+01	6.2E+01					
Great B. heron	3.2E+01	4.3E+01			4.7E+01	6.2E+01					
Mallard	3.9E+01	5.1E+01									
Lesser scaup	4.3E+01	5.7E+01									
Kingfisher	6.5E+01	8.5E+01			4.7E+01	6.2E+01					
Spotted sandpiper	8.8E+01	1.2E+02									
Herring gull	3.9E+01	5.2E+01									
Red-tailed hawk	3.9E+01	5.1E+01									
Amer. Kestrel	4.4E+01	5.8E+01			4.7E+01	6.2E+01					
Northern bobwhite	6.2E+01	8.2E+01									
Amer. Robin	7.5E+01	9.9E+01			4.7E+01	6.2E+01					
Amer. Woodcock	6.3E+01	8.2E+01			4.7E+01	6.2E+01					

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks			reference
Lead	NOAEL	LOAEL			NOAEL	LOAEL			Endpoint / Dose	TRV	
			Krasovskii et al., 1979				Sample et al., 1996				EPA, 1997
Rat	***5.0E-03***	5.0E-02		Rat	***8.0E+00***	8.0E+01		Sheep	LOAEL / 0.5	5.0E-03	
Mink	***3.2E-03***	3.2E-02			***6.2E+00***	6.2E+01					
River otter	***2.0E-03***	2.0E-02			***3.7E+00***	3.7E+01					
Short-tailed shrew	***9.6E-03***	9.6E-02			***1.8E+01***	1.8E+02					
Deer mouse	***9.3E-03***	9.3E-02									
Meadow vole	***7.7E-03***	7.7E-02			***1.3E+01***	1.3E+02					
Eastern cottontail	***3.4E-03***	3.4E-02			***5.9E+00***	5.9E+01					
Red fox	***2.3E-03***	2.3E-02			***4.2E+00***	4.2E+01					
Raccoon	***2.2E-03***	2.2E-02									
White-t deer	***1.1E-03***	1.1E-02			***2.2E+00***	2.2E+01					
			Eden and Garlich, 1983				Sample et al., 1996				EPA, 1997
Quail	***2.1E-02***	2.1E-01		Quail	1.1E+00	1.1E+01		Dove	LOAEL/0.012	1.2E-04	
Bald eagle	***8.8E-03***	8.8E-02									
Osprey	***1.1E-02***	1.1E-01			1.1E+00	1.1E+01					
Great B. heron	***1.1E-02***	1.1E-01			1.1E+00	1.1E+01					
Mallard	***1.3E-02***	1.3E-01									
Lesser scaup	***1.4E-02***	1.4E-01									
Kingfisher	***2.1E-02***	2.1E-01			1.1E+00	1.1E+01					
Spotted sandpiper	***2.8E-02***	2.8E-01									
Herring gull	***1.3E-02***	1.3E-01									
Red-tailed hawk	***1.2E-02***	1.2E-01			1.1E+00	1.1E+01					
Amer. Kestrel	***1.2E-02***	1.2E-01									
Northern bobwhite	***2.0E-02***	2.0E-01									
Amer. Robin	***2.4E-02***	2.4E-01			1.1E+00	1.1E+01					
Amer. Woodcock	***1.9E-02***	1.9E-01			1.1E+00	1.1E+01					

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference		Oak Ridge National Lab Screening Benchmarks		reference		OSW Screening Level Benchmarks		reference
Mercury	NOAEL	LOAEL			NOAEL	LOAEL			Endpoint / Dose	TRV	
			Dougherty, 1974				Sample et al., 1996				EPA, 1997
Monkey	1.6E-01	5.0E-01		Rat	3.2E-02	1.6E-01		Rat	NOAEL / 0.024	2.4E-02	
Mink	3.0E-01	9.5E-01			1.5E-02	2.5E-02					
River otter	1.7E-01	5.3E-01			9.0E-03	1.5E-02					
Short-tailed shrew	7.7E-01	2.4E+00			7.0E-02	3.5E-01					
Deer mouse	7.5E-01	2.3E+00									
Meadow vole	6.3E-01	2.0E+00			5.4E-02	2.7E-01					
Eastern cottontail	2.6E-01	8.2E-01			2.4E-02	1.2E-01					
Red fox	2.0E-01	6.1E-01			1.0E-02	1.7E-02					
Raccoon	1.9E-01	5.9E-01									
White-t deer	9.4E-02	2.9E-01			9.0E-03	4.5E-02					
			Heinz, 1974; 1975; 1979				Sample et al., 1996				EPA, 1997
Mallard	***6.4E-03***	6.4E-02		Mallard	***6.4E-03***	6.4E-02		Mallard	LOAEL/0.5	5.0E-02	
Bald eagle	***4.8E-03***	4.8E-02									
Osprey	***5.9E-03***	5.9E-02			***6.4E-03***	6.4E-02					
Great B. heron	***5.4E-03***	5.4E-02			***6.4E-03***	6.4E-02					
Mallard	***6.4E-03***	6.4E-02									
Lesser scaup	***7.1E-03***	7.1E-02									
Kingfisher	***1.1E-02***	1.1E-01			***6.4E-03***	6.4E-02					
Spotted sandpiper	***1.5E-02***	1.5E-01									
Herring gull	***6.5E-03***	6.5E-02									
Red-tailed hawk	***6.4E-03***	6.4E-02			***6.4E-03***	6.4E-02					
Amer. Kestrel	***7.3E-03***	7.3E-02									
Northern bobwhite	***1.0E-02***	1.0E-01									
Amer. Robin	***1.2E-02***	1.2E-01			***6.4E-03***	6.4E-02					
Amer. Woodcock	***1.0E-02***	1.0E-01			***6.4E-03***	6.4E-02					

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks		reference
Molybdenum	NOAEL	LOAEL			NOAEL	LOAEL		Endpoint / Dose	TRV	
			Fungwe et al., 1990				Sample et al., 1996			
Rat	9.0E-01	1.8E+00		Mouse	***2.6E-01***	2.6E+00		Not available		
Mink	5.6E-01	1.1E+00			***1.1E-01***	1.1E+00				
River otter	3.1E-01	6.2E-01			***6.0E-02***	6.4E-01				
Short-tailed shrew	1.4E+00	2.8E+00			***3.1E-01***	3.1E+00				
Deer mouse	1.4E+00	2.8E+00								
Meadow vole	1.2E+00	2.3E+00			***2.4E-01***	2.4E+00				
Eastern cottontail	4.9E-01	9.8E-01			***1.0E-01***	1.0E+00				
Red fox	3.6E-01	7.3E-01			***7.0E-02***	7.4E-01				
Raccoon	3.5E-01	7.0E-01								
White-t deer	1.7E-01	3.5E-01			***4.0E-02***	3.9E-01				
			Sample et al., 1996				Sample et al., 1996			
Chicken	3.5E+00	3.5E+01		Chicken	3.5E+00	3.5E+01		Not available		
Bald eagle	1.6E+00	1.6E+01								
Osprey	1.9E+00	1.9E+01			3.5E+00	3.5E+01				
Great B. heron	1.7E+00	1.7E+01			3.5E+00	3.5E+01				
Mallard	2.1E+00	2.1E+01								
Lesser scaup	2.3E+00	2.3E+01								
Kingfisher	3.5E+00	3.5E+01			3.5E+00	3.5E+01				
Spotted sandpiper	4.8E+00	4.8E+01								
Herring gull	2.1E+00	2.1E+01								
Red-tailed hawk	2.1E+00	2.1E+01			3.5E+00	3.5E+01				
Amer. Kestrel	2.4E+00	2.4E+01								
Northern bobwhite	3.3E+00	3.3E+01								
Amer. Robin	4.0E+00	4.0E+01			3.5E+00	3.5E+01				
Amer. Woodcock	3.4E+00	3.4E+01			3.5E+00	3.5E+01				

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks			reference
Nickel	NOAEL	LOAEL			NOAEL	LOAEL			Endpoint / Dose	TRV	
			Ambrose et al., 1976				Sample et al., 1996				EPA, 1997
Rat	5.4E+01	1.1E+02		Rat	***4.0E+01***	8.0E+01		Rat	NOAEL / 1.12	######	
Mink	3.3E+01	6.6E+01			***3.1E+01***	6.2E+01					
River otter	2.0E+01	3.9E+01			***1.8E+01***	3.7E+01					
Short-tailed shrew	9.2E+01	1.8E+02			***8.8E+01***	1.8E+02					
Deer mouse	8.9E+01	1.8E+02									
Meadow vole	7.8E+01	1.6E+02			***6.7E+01***	1.3E+02					
Eastern cottontail	3.2E+01	6.3E+01			***2.9E+01***	5.9E+01					
Red fox	2.3E+01	4.5E+01			***2.1E+01***	4.2E+01					
Raccoon	2.2E+01	4.3E+01									
White-t deer	1.1E+01	2.2E+01			***1.1E+01***	2.2E+01					
			Sample et al., 1996				Sample et al., 1996				
Mallard	7.7E+01	1.1E+02		Mallard	7.7E+01	1.1E+02		not available			
Bald eagle	5.2E+01	7.2E+01									
Osprey	6.4E+01	8.9E+01			7.7E+01	1.1E+02					
Great B. heron	5.9E+01	8.1E+01			7.7E+01	1.1E+02					
Mallard	7.0E+01	9.7E+01									
Lesser scaup	7.8E+01	1.1E+02									
Kingfisher	1.2E+02	1.6E+02			7.7E+01	1.1E+02					
Spotted sandpiper	1.6E+02	2.2E+02									
Herring gull	7.1E+01	9.8E+01									
Red-tailed hawk	7.1E+01	9.8E+01			7.7E+01	1.1E+02					
Amer. Kestrel	7.2E+01	1.0E+02									
Northern bobwhite	1.1E+02	1.6E+02									
Amer. Robin	1.4E+02	1.9E+02			7.7E+01	1.1E+02					
Amer. Woodcock	1.1E+02	1.6E+02			7.7E+01	1.1E+02					

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks			reference
Selenium	NOAEL	LOAEL			NOAEL	LOAEL			Endpoint / Dose	TRV	
			Rosenfeld and Beath, 1954				Sample et al., 1996				EPA, 1997
Rat	2.0E-01	3.4E-01		Rat	***2.0E-01***	3.3E-01		Rat	LOAEL / 0.34	3.4E-03	
Mink	1.7E-01	2.8E-01			***1.5E-01***	2.5E-01					
River otter	9.2E-02	1.5E-01			***9.1E-02***	1.5E-01					
Short-tailed shrew	4.2E-01	7.0E-01			***4.4E-01***	7.3E-01					
Deer mouse	4.1E-01	6.9E-01									
Meadow vole	3.4E-01	5.7E-01			***3.4E-01***	5.5E-01					
Eastern cottontail	1.4E-01	2.4E-01			***1.5E-01***	2.4E-01					
Red fox	1.1E-01	1.8E-01			***1.1E-01***	1.7E-01					
Raccoon	1.0E-01	1.7E-01									
White-t deer	5.2E-02	8.6E-02			***5.6E-02***	9.3E-02					
			Heinz et al., 1987				Sample et al., 1996				EPA, 1997
Mallard	5.0E-01	1.0E+00		Mallard	5.0E-01	1.0E+00		Mallard	LOAEL/10.57	5.7E-03	
Bald eagle	3.6E-01	7.3E-01									
Osprey	4.5E-01	9.0E-01			5.0E-01	1.0E+00					
Great B. heron	4.1E-01	8.2E-01			5.0E-01	1.0E+00					
Mallard	4.9E-01	9.8E-01									
Lesser scaup	5.4E-01	1.1E+00									
Kingfisher	8.2E-01	1.6E+00			5.0E-01	1.0E+00					
Spotted sandpiper	1.1E+00	2.2E+00									
Herring gull	5.0E-01	9.9E-01									
Red-tailed hawk	4.9E-01	9.8E-01			5.0E-01	1.0E+00					
Amer. Kestrel	5.5E-01	1.1E+00									
Northern bobwhite	7.9E-01	1.6E+00									
Amer. Robin	9.5E-01	1.9E+00			5.0E-01	1.0E+00					
Amer. Woodcock	7.9E-01	1.6E+00			5.0E-01	1.0E+00					

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks		reference	OSW Screening Level Benchmarks			reference
Silver	NOAEL	LOAEL		NOAEL	LOAEL			Endpoint / Dose	TRV	
										EPA, 1997
appropriate studies not identified				not available			Mouse	LOAEL / 18.1	#######	
Mink	ID	ID								
River otter	ID	ID								
Short-tailed shrew	ID	ID								
Deer mouse	ID	ID								
Meadow vole	ID	ID								
Eastern cottontail	ID	ID								
Red fox	ID	ID								
Raccoon	ID	ID								
White-t deer	ID	ID								
										EPA, 1997
appropriate studies not identified				not available			Bobwhit	LD50/2.2E+06	#######	
Bald eagle	ID	ID								
Osprey	ID	ID								
Great B. heron	ID	ID								
Mallard	ID	ID								
Lesser scaup	ID	ID								
Kingfisher	ID	ID								
Spotted sandpiper	ID	ID								
Herring gull	ID	ID								
Red-tailed hawk	ID	ID								
Amer. Kestrel	ID	ID								
Northern bobwhite	ID	ID								
Amer. Robin	ID	ID								
Amer. Woodcock	ID	ID								

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks			reference
Thallium	NOAEL	LOAEL			NOAEL	LOAEL			Endpoint / Dose	TRV	
							Sample et al., 1996				EPA, 1997
appropriate studies not identified				Rat	***7.4E-03***	7.4E-02		Rat	LOAEL / 0.7	7E-03	
Mink	ID	ID			***6.0E-03***	5.8E-02					
River otter	ID	ID			***3.0E-03***	3.4E-02					
Short-tailed shrew	ID	ID			***1.6E-02***	1.6E-01					
Deer mouse	ID	ID									
Meadow vole	ID	ID			***1.3E-02***	1.3E-01					
Eastern cottontail	ID	ID			***5.0E-03***	5.5E-02					
Red fox	ID	ID			***4.0E-03***	3.9E-02					
Raccoon	ID	ID									
White-t deer	ID	ID			***2.0E-03***	2.1E-02					
appropriate studies not identified				not available				not available			
Bald eagle	ID	ID									
Osprey	ID	ID									
Great B. heron	ID	ID									
Mallard	ID	ID									
Lesser scaup	ID	ID									
Kingfisher	ID	ID									
Spotted sandpiper	ID	ID									
Herring gull	ID	ID									
Red-tailed hawk	ID	ID									
Amer. Kestrel	ID	ID									
Northern bobwhite	ID	ID									
Amer. Robin	ID	ID									
Amer. Woodcock	ID	ID									

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks		reference
Vanadium	NOAEL	LOAEL			NOAEL	LOAEL		Endpoint / Dose	TRV	
			Domingo et al, 1986				Sample et al., 1996			
Rat	***5.0E-01***	5.0E+00		Rat	2.1E-01	2.1E+00		Not available		
Mink	***4.2E-01***	4.2E+00			1.5E-01	1.5E+00				
River otter	***2.3E-01***	2.3E+00			8.9E-02	8.9E-01				
Short-tailed shrew	***1.1E+00***	1.1E+01			4.3E-01	4.3E+00				
Deer mouse	***1.0E+00***	1.0E+01								
Meadow vole	***8.6E-01***	8.6E+00			3.3E-01	3.3E+00				
Eastern cottontail	***3.6E-01***	3.6E+00			1.4E-01	1.4E+00				
Red fox	***2.7E-01***	2.7E+00			1.0E-01	1.0E+00				
Raccoon	***2.6E-01***	2.6E+00								
White-t deer	***1.3E-01***	1.3E+00			5.5E-02	5.5E-01				
			Romoser et al., 1961				Sample et al., 1996			
Chick	1.5E+00	2.2E+00		Mallard	1.1E+01	ID		Not available		
Bald eagle	9.5E-01	1.4E+00								
Osprey	1.1E+00	1.7E+00			1.1E+01	ID				
Great B. heron	9.9E-01	1.5E+00			1.1E+01	ID				
Mallard	1.2E+00	1.8E+00			1.1E+01	ID				
Lesser scaup	1.3E+00	1.9E+00								
Kingfisher	2.0E+00	3.0E+00			1.1E+01	ID				
Spotted sandpiper	2.8E+00	4.2E+00								
Herring gull	1.2E+00	1.8E+00								
Red-tailed hawk	1.2E+00	1.8E+00			1.1E+01	ID				
Amer. Kestrel	1.4E+00	2.0E+00								
Northern bobwhite	2.0E+00	2.9E+00								
Amer. Robin	2.3E+00	3.5E+00			1.1E+01	ID				
Amer. Woodcock	2.0E+00	3.0E+00			1.1E+01	ID				

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.1 Avian and Mammalian Benchmarks for Metals (mg/kg-day)

Constituent	OSW HWIR Screening Benchmarks		reference	Oak Ridge National Lab Screening Benchmarks			reference	OSW Screening Level Benchmarks			reference
Zinc	NOAEL	LOAEL			NOAEL	LOAEL			Endpoint / Dose	TRV	
			Schlicker and Cox, 1968				Sample et al., 1996				EPA, 1997
Rat	2.0E+02	4.1E+02		Rat	***1.6E+02***	3.2E+02		Mouse	NOAEL / 104	1.0E+01	
Mink	1.4E+02	2.9E+02			***1.2E+02***	2.5E+02					
River otter	8.0E+01	1.6E+02			***7.3E+01***	1.5E+02					
Short-tailed shrew	3.6E+02	7.2E+02			***3.5E+02***	7.0E+02					
Deer mouse	3.5E+02	7.1E+02									
Meadow vole	3.0E+02	5.9E+02			***2.7E+02***	5.4E+02					
Eastern cottontail	1.2E+02	2.5E+02			***1.2E+02***	2.4E+02					
Red fox	9.2E+01	1.8E+02			***8.5E+01***	1.7E+02					
Raccoon	8.9E+01	1.8E+02									
White-t deer	4.4E+01	8.9E+01			***4.5E+01***	9.0E+01					
			Sample et al., 1996				Sample et al., 1996				EPA, 1997
Hen	1.1E+01	9.4E+01		Hen	1.5E+01	1.3E+02		Chicken	NOAEL/6.6	6.6E+00	
Bald eagle	8.9E+00	7.9E+01									
Osprey	1.1E+01	9.8E+01			1.5E+01	1.3E+02					
Great B. heron	1.0E+01	8.9E+01			1.5E+01	1.3E+02					
Mallard	1.2E+01	1.1E+02									
Lesser scaup	1.3E+01	1.2E+02									
Kingfisher	2.0E+01	1.8E+02			1.5E+01	1.3E+02					
Spotted sandpipe	2.7E+01	2.4E+02									
Herring gull	1.2E+01	1.1E+02									
Red-tailed hawk	1.2E+01	1.1E+02			1.5E+01	1.3E+02					
Amer. Kestrel	1.4E+01	1.2E+02									
Northern bobwhite	1.9E+01	1.7E+02									
Amer. Robin	2.3E+01	2.1E+02			1.5E+01	1.3E+02					
Amer. Woodcock	1.9E+01	1.7E+02			1.5E+01	1.3E+02					

TRV: Toxicity Reference Value
NOAELs in italicized bold were extrapolated from LOAEL (NOAEL = LOAEL/10)
ID: Insufficient Data
Shading indicates values are derived from experimental studies.

Table 4.2 Sediment and Surface Water Concentrations Corresponding to No Effects (NOAELs) and Low Effects (LOAELs) Levels for Mammals and Birds Typical of Freshwater Ecosystems (mg/kg sediment and mg/L water)

Constituent	Mink		River Otter		Bald Eagle	
	NOAEL	LOAEL	NOAEL	LOAEL	NOAEL	LOAEL
	(surface water)	(surface water)	(surface water)	(surface water)	(surface water)	(surface water)
Aluminum	no BCF/benmrk	no BCF/benmrk	no BCF/benmrk	no BCF/benmrk	no BCF/benmrk	no BCF/benmrk
Antimony	1.6E+00	1.6E+01	7.0E-01	7.0E+00	no benmrk	no benmrk
Arsenic	6.6E+00	1.3E+01	3.3E+00	7.7E+00	5.2E-02	2.1E-01
Barium	no benmrk	no benmrk	no benmrk	no benmrk	2.5E+02	4.9E+02
Beryllium	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Boron	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Cadmium	1.8E-02	1.8E-01	1.1E-02	1.1E-01	3.6E-02	3.6E-01
Chromium	6.0E+00	6.0E+01	4.5E+00	8.4E+01	7.0E+00	3.5E+01
Cobalt	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Copper	9.1E+01	1.2E+02	4.0E+01	5.1E+01	8.0E+02	1.1E+03
Lead	4.4E-04	4.4E-03	3.0E-04	3.0E-03	1.6E-03	1.6E-02
Mercury	2.9E-05	8.9E-05	2.2E-06	6.8E-06	6.0E-07	6.0E-06
Molybdenum	8.1E+00	1.6E+01	3.5E+00	7.1E+00	4.3E+01	4.3E+02
Nickel	1.6E+02	3.2E+02	9.5E+01	3.1E+02	4.0E+02	5.5E+02
Selenium	2.1E-03	3.6E-03	2.6E-04	4.4E-04	6.3E-03	1.3E-02
Silver	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Thallium	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Vanadium	6.0E+00	6.0E+01	2.6E+00	2.6E+01	2.6E+01	3.9E+01
Zinc	1.8E+02	3.7E+02	9.3E+01	2.1E+02	1.6E+01	1.4E+02

Table 4.2 Sediment and Surface Water Concentrations Corresponding to No Effects (NOAELs) and Low Effects (LOAELs) Levels for Mammals and Birds Typical of Freshwater Ecosystems (mg/kg sediment and mg/L water)

Constituent	Eagle	Osprey		Great Blue heron		Mallard	
	LOAEL	NOAEL	LOAEL	NOAEL	LOAEL	NOAEL	LOAEL
	(surface water)	(surface water)	(surface water)	(surface water)	(surface water)	(surface water)	(surface water)
Aluminum	no BCF/benmrk	no BCF/benmrk	no BCF/benmrk	no BCF/benmrk	no BCF/benmrk	no BCF/benmrk	no BCF/benmrk
Antimony	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no BCF/benmrk	no BCF/benmrk
Arsenic	2.1E-01	3.7E-02	1.5E-01	3.9E-02	1.6E-01	no BCF	no BCF
Barium	4.9E+02	2.1E+02	4.2E+02	2.2E+02	4.5E+02	no BCF	no BCF
Beryllium	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no BCF/benmrk	no BCF/benmrk
Boron	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Cadmium	3.6E-01	2.5E-02	2.5E-01	2.7E-02	2.7E-01	no BCF	no BCF
Chromium	3.5E+01	5.2E+00	2.6E+01	5.6E+00	2.8E+01	no BCF	no BCF
Cobalt	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Copper	1.1E+03	6.8E+02	9.0E+02	7.2E+02	9.5E+02	no BCF	no BCF
Lead	1.6E-02	1.2E-03	1.2E-02	1.3E-03	1.3E-02	no BCF	no BCF
Mercury	6.0E-06	4.2E-07	4.2E-06	4.5E-07	4.5E-06	no BCF	no BCF
Molybdenum	4.3E+02	3.7E+01	3.7E+02	3.9E+01	3.9E+02	no BCF	no BCF
Nickel	5.5E+02	2.9E+02	4.0E+02	3.1E+02	4.3E+02	no BCF	no BCF
Selenium	1.3E-02	4.4E-03	8.8E-03	4.7E-03	9.4E-03	no BCF	no BCF
Silver	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no BCF/benmrk	no BCF/benmrk
Thallium	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Vanadium	3.9E+01	2.2E+01	3.2E+01	2.2E+01	3.3E+01	no BCF	no BCF
Zinc	1.4E+02	1.1E+01	1.0E+02	1.2E+01	1.1E+02	no BCF	no BCF

Table 4.2 Sediment and Surface Water Concentrations Corresponding to No Effects (NOAELs) and Low Effects (LOAELs) Levels for Mammals and Birds Typical of Freshwater Ecosystems (mg/kg sediment and mg/L water)

Constituent	Lesser Scaup		Kingfisher		Spotted Sandpiper	
	NOAEL	LOAEL	NOAEL	LOAEL	NOAEL	LOAEL
	(surface water)	(surface water)	(surface water)	(surface water)	(surface water)	(surface water)
Aluminum	no BCF/benmrk	no BCF/benmrk	no BCF/benmrk	no BCF/benmrk	no BCF/benmrk	no BCF/benmrk
Antimony	no BCF/benmrk	no BCF/benmrk	no benmrk	no benmrk	no BCF/benmrk	no BCF/benmrk
Arsenic	no BCF	no BCF	2.9E-02	1.1E-01	no BCF	no BCF
Barium	no BCF	no BCF	1.8E+02	3.6E+02	no BCF	no BCF
Beryllium	no BCF/benmrk	no BCF/benmrk	no benmrk	no benmrk	no BCF/benmrk	no BCF/benmrk
Boron	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Cadmium	no BCF	no BCF	1.9E-02	1.9E-01	no BCF	no BCF
Chromium	no BCF	no BCF	4.1E+00	2.1E+01	no BCF	no BCF
Cobalt	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Copper	no BCF	no BCF	5.9E+02	7.7E+02	no BCF	no BCF
Lead	no BCF	no BCF	9.0E-04	9.0E-03	no BCF	no BCF
Mercury	no BCF	no BCF	3.2E-07	3.2E-06	no BCF	no BCF
Molybdenum	no BCF	no BCF	3.2E+01	3.2E+02	no BCF	no BCF
Nickel	no BCF	no BCF	2.3E+02	3.2E+02	no BCF	no BCF
Selenium	no BCF	no BCF	3.4E-03	6.7E-03	no BCF	no BCF
Silver	no BCF/benmrk	no BCF/benmrk	no benmrk	no benmrk	no BCF/benmrk	no BCF/benmrk
Thallium	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Vanadium	no BCF	no BCF	1.8E+01	2.8E+01	no BCF	no BCF
Zinc	no BCF	no BCF	8.6E+00	7.7E+01	no BCF	no BCF

Table 4.2 Sediment and Surface Water Concentrations Corresponding to No Effects (NOAELs) and Low Effects (LOAELs) Levels for Mammals and Birds Typical of Freshwater Ecosystems (mg/kg sediment and mg/L water)

Constituent	Herring Gull		Spotted Sandpiper	
	NOAEL	LOAEL	NOAEL	LOAEL
	(surface water)	(surface water)	(sediment)	(sediment)
Aluminum	no BCF/benmrk	no BCF/benmrk	no benmrk	no benmrk
Antimony	no benmrk	no benmrk	no benmrk	no benmrk
Arsenic	4.3E-02	1.7E-01	5.1E-01	2.0E+00
Barium	2.1E+02	4.3E+02	1.9E+02	3.9E+02
Beryllium	no benmrk	no benmrk	no benmrk	no benmrk
Boron	no benmrk	no benmrk	no benmrk	no benmrk
Cadmium	3.0E-02	3.0E-01	2.5E+01	2.5E+02
Chromium	5.9E+00	3.0E+01	1.7E+01	8.3E+01
Cobalt	no benmrk	no benmrk	no benmrk	no benmrk
Copper	6.9E+02	9.1E+02	6.3E+02	8.3E+02
Lead	1.4E-03	1.4E-02	2.2E-01	2.2E+00
Mercury	5.0E-07	5.0E-06	1.0E-01	1.0E+00
Molybdenum	3.7E+01	3.7E+02	3.4E+01	3.4E+02
Nickel	3.3E+02	4.6E+02	1.1E+03	1.6E+03
Selenium	5.2E-03	1.0E-02	8.0E+00	1.6E+01
Silver	no benmrk	no benmrk	no benmrk	no benmrk
Thallium	no benmrk	no benmrk	no benmrk	no benmrk
Vanadium	2.2E+01	3.3E+01	1.8E+01	2.7E+01
Zinc	1.3E+01	1.2E+02	2.0E+02	1.7E+03

Table 4.3 Soil Concentrations Corresponding to No Effect (NOAELs) and Low Effect (LOAELs) Levels for Mammals and Birds Typical of Terrestrial Ecosystems (mg/kg soil)

Constituent	Meadow vole		Eastern cottontail		Whitetailed deer		Northern Bobwhite	
	NOAEL	LOAEL	NOAEL	LOAEL	NOAEL	LOAEL	NOAEL	LOAEL
Aluminum	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Antimony	2.9E+01	2.9E+02	1.9E+01	1.9E+02	6.4E+01	6.4E+02	no benmrk	no benmrk
Arsenic	9.1E+02	1.8E+03	5.6E+02	1.1E+03	2.0E+03	3.9E+03	6.6E+00	2.6E+01
Barium	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	2.6E+03	5.3E+03
Beryllium	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Boron	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Cadmium	5.0E+01	5.0E+02	3.0E+01	3.0E+02	1.0E+02	1.0E+03	8.5E+01	8.5E+02
Chromium	3.6E+02	3.6E+03	2.3E+02	2.3E+03	8.1E+02	8.1E+03	2.3E+02	1.1E+03
Cobalt	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Copper	1.1E+03	1.5E+03	7.0E+02	9.0E+02	2.4E+03	3.1E+03	6.6E+03	8.6E+03
Lead	1.6E+00	1.6E+01	1.0E+00	1.0E+01	3.6E+00	3.6E+01	5.2E+00	5.2E+01
Mercury	8.0E+01	2.5E+02	5.0E+01	1.6E+02	1.7E+02	5.5E+02	1.4E+00	1.4E+01
Molybdenum	1.5E+02	3.0E+02	9.4E+01	1.9E+02	3.2E+02	6.5E+02	4.6E+02	4.6E+03
Nickel	6.1E+03	1.2E+04	3.6E+03	7.3E+03	1.3E+04	2.5E+04	1.1E+04	1.5E+04
Selenium	1.7E+00	2.8E+00	1.1E+00	1.8E+00	3.6E+00	6.1E+00	4.7E+00	9.5E+00
Silver	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Thallium	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Vanadium	1.1E+02	1.1E+03	6.9E+01	6.9E+02	2.4E+02	2.4E+03	2.7E+02	4.1E+02
Zinc	1.4E+04	2.8E+04	8.5E+03	1.7E+04	2.9E+04	5.9E+04	1.1E+03	9.7E+03

Table 4.3 Soil Concentrations Corresponding to No Effect (NOAELs) and Low Effect (LOAELs) Levels for Mammals and Birds Typical of Terrestrial Ecosystems (mg/kg soil)

Constituent	Short-tailed shrew		Deer mouse		Red fox		Raccoon	
	NOAEL	LOAEL	NOAEL	LOAEL	NOAEL	LOAEL	NOAEL	LOAEL
Aluminum	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Antimony	5.1E+01	5.1E+02	7.2E+01	7.2E+02	3.6E+01	3.6E+02	1.4E+01	1.4E+02
Arsenic	5.9E+03	1.2E+04	5.0E+03	1.0E+04	2.1E+04	4.2E+04	1.5E+03	2.9E+03
Barium	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Beryllium	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Boron	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Cadmium	2.9E+01	2.9E+02	2.6E+02	2.6E+03	4.8E+01	4.8E+02	5.9E+01	5.9E+02
Chromium	6.5E+02	6.5E+03	7.7E+02	7.7E+03	1.3E+03	1.3E+04	5.2E+03	5.2E+04
Cobalt	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Copper	4.3E+03	5.6E+03	6.2E+03	8.0E+03	1.9E+03	2.4E+03	1.5E+03	1.9E+03
Lead	3.2E+00	3.2E+01	7.8E+00	7.8E+01	3.8E+00	3.8E+01	2.3E+00	2.3E+01
Mercury	2.2E+01	6.8E+01	2.0E+02	6.2E+02	5.3E+02	1.6E+03	2.0E+03	6.2E+03
Molybdenum	2.6E+02	5.2E+02	3.7E+02	7.3E+02	1.8E+02	3.6E+02	7.1E+01	1.4E+02
Nickel	1.0E+04	2.0E+04	3.2E+04	6.4E+04	1.4E+04	2.7E+04	8.4E+03	1.7E+04
Selenium	2.0E+01	3.3E+01	9.4E+00	1.6E+01	2.4E+01	4.0E+01	2.7E+00	4.5E+00
Silver	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Thallium	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Vanadium	1.9E+02	1.9E+03	2.7E+02	2.7E+03	1.3E+02	1.3E+03	5.3E+01	5.3E+02
Zinc	1.5E+04	3.0E+04	7.6E+04	1.5E+05	1.7E+04	3.4E+04	1.7E+04	3.4E+04

Table 4.3 Soil Concentrations Corresponding to No Effect (NOAELs) and Low Effect (LOAELs) Levels for Mammals and Birds Typical of Terrestrial Ecosystems (mg/kg soil)

Constituent	Red-tailed hawk		American kestrel		American robin		American woodcock	
	NOAEL	LOAEL	NOAEL	LOAEL	NOAEL	LOAEL	NOAEL	LOAEL
Aluminum	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Antimony	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Arsenic	2.1E+03	8.6E+03	2.4E+03	9.7E+03	3.8E+01	1.5E+02	1.3E+00	5.2E+00
Barium	1.1E+05	2.2E+05	1.2E+05	2.5E+05	1.9E+03	3.9E+03	2.4E+02	4.8E+02
Beryllium	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Boron	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Cadmium	3.9E+02	3.9E+03	2.6E+02	2.6E+03	4.9E+02	4.9E+03	1.1E+00	1.1E+01
Chromium	3.1E+03	1.6E+04	1.9E+03	9.6E+03	1.6E+02	8.2E+02	9.6E+00	4.8E+01
Cobalt	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Copper	3.8E+04	4.9E+04	2.7E+04	3.6E+04	3.8E+04	5.0E+04	6.5E+02	8.5E+02
Lead	3.9E+01	3.9E+02	2.8E+01	2.8E+02	2.9E+01	2.9E+02	2.2E-01	2.2E+00
Mercury	3.4E+01	3.4E+02	2.5E+01	2.5E+02	1.0E+00	1.0E+01	9.2E-03	9.2E-02
Molybdenum	2.1E+03	2.1E+04	7.9E+02	7.9E+03	3.4E+02	3.4E+03	4.2E+01	4.2E+02
Nickel	1.2E+05	1.7E+05	8.0E+04	1.1E+05	6.2E+04	8.5E+04	4.2E+02	5.8E+02
Selenium	4.2E+02	8.4E+02	3.0E+02	6.1E+02	2.7E+01	5.4E+01	2.6E+00	5.2E+00
Silver	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Thallium	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk	no benmrk
Vanadium	1.2E+03	1.9E+03	4.4E+02	6.6E+02	1.9E+02	2.9E+02	2.5E+01	3.8E+01
Zinc	4.5E+03	4.0E+04	3.3E+03	2.9E+04	6.3E+03	5.6E+04	2.7E+01	2.4E+02

Table 5.1 Chemical Stressor Concentration Limits (CSCLs) for Metals: Soil, Sediment, and Surface Water

Constituent	Soil CSCLs (mg/kg)	Terrestrial Receptor	Sediment CSCLs (mg/kg)	Sediment Receptor	Total Aquatic CSCLs (mg/L)	Dissolved Aquatic CSCLs (mg/L)	Aquatic Receptor	Total Amphibian CSCLs (mg/L)
Aluminum	ID	--	ID	--	8.7E-02	--	Aquatic Biota	5.0E-01
Antimony	1.4E+01	raccoon	2.0E+00	Sediment biota	3.0E-02	--	Aquatic Biota	3.0E-01
Arsenic $_{total}$	1.0E+01	plants	5.1E-01	Spotted Sandpiper	2.9E-02	--	Kingfisher	4.3E+00
Arsenic III	ID	--	ID	--	1.5E-01	1.5E-01	Aquatic Biota	ID
Arsenic V	ID	--	ID	--	8.1E-03	8.1E-03	Aquatic Biota	ID
Barium	5.0E+02	plants	1.9E+02	Spotted Sandpiper	4.0E-03	--	Aquatic Biota	ID
Beryllium	ID	--	ID	--	6.6E-04	--	Aquatic Biota	ID
Boron	ID	--	ID	--	1.6E-03	--	Aquatic Biota	2.9E+01
Cadmium	1.0E+00	soil invertebrates	6.8E-01	Sediment biota	2.5E-03	2.3E-03	Aquatic Biota	1.9E+00
Chromium $_{total}$	6.4E+01	soil invertebrates	1.7E+01	Spotted Sandpiper	4.1E+00	--	Kingfisher	8.8E+00
Chromium III	ID	--	ID	--	8.6E-02	7.4E-02	Aquatic Biota	8.8E+00
Chromium VI	ID	--	ID	--	1.1E-02	1.1E-02	Aquatic Biota	ID
Cobalt	1.0E+03	soil invertebrates	ID	--	2.3E-02	--	Aquatic Biota	5.0E-02
Copper	2.1E+01	soil invertebrates	1.9E+01	Sediment biota	9.3E-03	8.9E-03	Aquatic Biota	1.1E+00
Lead	2.8E+01	soil invertebrates	2.2E-01	Spotted Sandpiper	3.0E-04	2.4E-04	River Otter	2.1E+00
Mercury	1.0E-01	soil invertebrates	1.0E-01	Spotted Sandpiper	1.9E-07	--	Kingfisher	2.0E-01
Molybdenum	4.2E+01	American woodcock	3.4E+01	Spotted Sandpiper	3.7E-01	--	Aquatic Biota	ID
Nickel	3.0E+01	plants	1.6E+01	Sediment biota	5.2E-02	5.2E-02	Aquatic Biota	2.2E+00
Selenium $_{total}$	1.0E+00	plants	ID	--	2.6E-04	--	River Otter	1.6E+00
Selenium IV	ID	--	ID	--	2.8E-02	--	Aquatic Biota	ID
Selenium VI	ID	--	ID	--	9.5E-03	--	Aquatic Biota	ID
Silver	ID	--	7.3E-01	Sediment biota	3.6E-04	--	Aquatic Biota	3.4E-02
Thallium	ID	--	ID	--	1.2E-02	--	Aquatic Biota	1.1E-01
Vanadium	6.9E+01	Eastern cottontail	1.8E+01	Spotted Sandpiper	2.0E-02	--	Aquatic Biota	ID
Zinc	5.0E+01	plants	1.2E+02	Sediment biota	1.2E-01	1.2E-01	Aquatic Biota	6.5E+00

ID: Insufficient Data

Table 6.1 Modeled Concentrations for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use Scenarios for Utility Coal Co-Managed Wastes: Landfill

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	5.1E+03	6.7E+00	5.0E-03	4.5E-03
Barium	2.0E+02	2.4E-01	4.7E-04	4.5E-04
Boron	1.0E-01	3.0E-03	1.0E-03	1.0E-03
Cadmium	2.4E-01	3.5E-04	2.2E-06	2.2E-06
Cobalt	1.4E-01	4.0E-04	9.0E-06	9.0E-06
Lead	7.6E+00	1.2E-02	9.8E-07	4.2E-08
Selenium $_{total}$	1.1E-01	2.4E-03	5.6E-04	5.6E-04
Silver	6.2E-04	6.9E-05	5.6E-07	1.7E-04
Thallium	2.5E-01	5.3E-04	7.2E-06	7.2E-06

Table 6.2 Modeled Concentrations for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use Scenarios for Utility Coal Co-Managed Wastes: Dewatered Surface Impoundment

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	1.1E+03	1.8E+00	1.4E-03	1.2E-03
Barium	3.8E+01	3.7E-02	7.2E-05	7.0E-05
Boron	2.2E-02	1.1E-05	3.5E-06	3.5E-06
Cadmium	5.1E-02	3.3E-05	2.1E-07	2.0E-07
Cobalt	6.9E-02	3.8E-05	8.4E-07	8.4E-07
Lead	1.3E+00	4.8E-03	4.0E-07	1.7E-08
$Selenium_{total}$	2.4E-02	1.2E-05	2.7E-06	2.7E-06
Silver	1.8E-04	6.1E-08	1.5E-07	1.5E-07
Thallium	7.1E-02	4.2E-05	5.7E-07	5.6E-07

Table 6.3 Modeled Concentrations for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use Scenarios for Utility Oil-Fired Wastes: Onsite Landfill

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	4.1E+01	7.1E-02	5.3E-05	4.7E-05
Arsenic $_{total}$	2.5E-02	7.9E-05	2.7E-06	2.7E-06
Boron	8.6E-04	9.5E-06	3.2E-06	3.2E-06
Cadmium	2.7E-03	4.3E-06	2.7E-08	2.6E-08
Chromium VI	1.8E-02	8.0E-05	4.5E-06	4.5E-06
Cobalt	3.6E-03	5.1E-06	1.1E-07	1.1E-07
Copper	1.4E-01	5.4E-04	2.4E-05	2.4E-05
Lead	9.8E-01	2.1E-03	1.7E-07	7.4E-09
Nickel	1.5E+00	2.8E-03	3.4E-05	3.4E-05
Silver	5.8E-06	3.9E-07	9.8E-07	9.8E-07
Vanadium	3.0E+00	6.9E-03	1.4E-04	1.4E-04
Zinc	7.6E-02	2.0E-04	4.9E-06	4.9E-06

Table 6.4 Modeled Concentrations for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use for Fluidized Bed Combined Wastes: Landfill

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	5.6E+02	7.4E-01	5.5E-04	4.9E-04
Boron	2.9E-03	8.4E-05	2.8E-05	2.8E-05
Cadmium	1.3E-02	1.8E-05	1.1E-07	1.1E-07
Cobalt	1.0E-02	2.9E-05	6.5E-07	6.4E-07
Lead	8.1E-01	1.3E-03	1.1E-07	4.6E-09
Nickel	7.4E-01	1.4E-03	1.8E-05	1.8E-05
Silver	5.6E-05	5.9E-06	1.5E-05	1.5E-05
Thallium	3.2E-02	6.6E-05	9.0E-07	8.9E-07
Vanadium	4.4E+00	1.2E-02	2.4E-04	2.4E-04

Table 6.5 Modeled Concentrations for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use Scenarios for Fluidized Bed Combustion Combined Wastes: Agricultural Soil Amendment

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	7.9E+00	2.2E-02	1.6E-05	1.5E-05
Boron	9.5E-05	4.4E-08	1.5E-08	1.5E-08
Cobalt	2.9E-04	1.6E-07	3.6E-09	3.6E-09
Nickel	2.1E-02	1.3E-05	1.6E-07	1.6E-07
Thallium	9.0E-04	5.5E-07	7.4E-09	7.4E-09
Vanadium	1.3E-01	7.2E-05	1.4E-06	1.4E-06

Table 6.6 Modeled Concentration for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use Scenarios for for Non-Utility Coal Co-Managed Wastes: Onsite Landfill

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	1.4E+02	1.9E-01	1.4E-04	1.3E-04
Barium	5.4E+00	6.7E-03	1.3E-05	1.3E-05
Boron	2.8E-03	7.9E-05	2.6E-05	2.6E-05
Cadmium	6.7E-03	9.8E-06	6.1E-08	6.1E-08
Cobalt	4.0E-03	1.1E-05	2.4E-07	2.4E-07
Lead	2.1E-01	3.4E-04	2.8E-08	1.2E-09
Selenium $_{total}$	3.0E-03	6.3E-05	1.5E-05	1.5E-05
Silver	1.7E-05	1.8E-06	4.4E-06	4.4E-06
Thallium	6.9E-03	1.4E-05	1.9E-07	1.9E-07

Table 6.7 Modeled Concentrations for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use Scenarios for Non-Utility Coal Co-Managed Wastes: Offsite Landfill

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	2.9E+03	3.7E+00	2.8E-03	2.5E-03
Barium	1.1E+02	1.3E-01	2.6E-04	2.5E-04
Boron	5.6E-02	1.7E-03	5.7E-04	5.7E-04
Cadmium	1.4E-01	2.0E-04	1.2E-06	1.2E-06
Cobalt	7.7E-02	2.2E-04	5.0E-06	5.0E-06
Lead	4.2E+00	6.5E-03	5.4E-07	2.3E-08
Selenium $_{total}$	6.1E-02	1.4E-03	3.2E-04	3.2E-04
Silver	3.5E-04	3.8E-05	9.6E-05	9.6E-05
Thallium	1.4E-01	2.9E-04	4.0E-06	4.0E-06

Table 6.8 Modeled Concentrations for Constituents in Soil, Sediment, and Surface Water Using Central Tendency Management/Use Scenarios for Utility Coal Co-Managed Wastes: Landfill

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	4.7E+02	6.2E-01	4.6E-04	4.1E-04
Barium	3.7E+00	4.6E-03	9.0E-06	8.6E-06
Boron	7.2E-03	2.1E-04	7.0E-05	7.0E-05
Cadmium	1.3E-02	1.8E-05	1.1E-07	1.1E-07
Cobalt	2.3E-02	6.7E-05	1.5E-06	1.5E-06
Lead	2.4E-01	3.8E-04	3.2E-08	1.4E-09
Selenium $_{total}$	4.8E-04	1.0E-05	2.4E-06	2.4E-06
Silver	5.9E-05	6.3E-06	1.6E-05	1.6E-05
Thallium	2.4E-02	5.1E-05	6.9E-07	6.9E-07

Table 6.9 Modeled Concentrations for Constituents in Soil, Sediment, and Surface Water Using Central Tendency Management/Use Scenarios for Utility Coal Co-Managed Wastes: Dewatered Surface Impoundment

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	3.4E+01	1.0E-01	7.8E-05	7.0E-05
Barium	2.7E-01	7.4E-04	1.5E-06	1.4E-06
Boron	5.4E-04	1.1E-06	3.8E-07	3.8E-07
Cadmium	9.3E-04	2.2E-06	1.4E-08	1.4E-08
Cobalt	1.7E-03	3.9E-06	8.7E-08	8.6E-08
Lead	1.8E-02	6.4E-05	5.4E-09	2.3E-10
$Selenium_{total}$	3.5E-05	7.7E-08	1.8E-08	1.8E-08
Silver	4.4E-06	6.5E-09	1.6E-08	1.6E-08
Thallium	1.8E-03	4.2E-06	5.7E-08	5.6E-08

Table 6.10 Modeled Concentrations for Constituents in Soil, Sediment, and Surface Water Using Central Tendency Management/Use Scenarios for Utility Oil-Fired Wastes: Onsite Landfill

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	4.7E+00	6.5E-03	4.8E-06	4.3E-06
Arsenic $_{total}$	3.0E-04	1.2E-06	4.0E-08	4.0E-08
Arsenic III	3.0E-04	1.2E-06	4.0E-08	4.0E-08
Arsenic V	3.0E-04	1.2E-06	4.0E-08	4.0E-08
Boron	3.3E-04	9.3E-06	3.1E-06	3.1E-06
Cadmium	3.3E-04	5.1E-07	3.2E-09	3.2E-09
Chromium VI	4.1E-03	2.4E-05	1.3E-06	1.3E-06
Cobalt	1.4E-03	4.0E-06	9.0E-08	9.0E-08
Copper	7.7E-03	3.7E-05	1.7E-06	1.7E-06
Lead	1.4E-01	2.3E-04	1.9E-08	8.1E-10
Nickel	3.5E-01	6.8E-04	8.4E-06	8.3E-06
Silver	1.1E-06	1.1E-07	2.7E-07	2.7E-07
Vanadium	8.6E-01	2.3E-03	4.6E-05	4.6E-05
Zinc	1.1E-02	3.4E-05	8.5E-07	8.5E-07

Table 6.11 Modeled Concentrations for Constituents in Soil, Sediment, and Surface Water Using Central Tendency Management/Use Scenarios for Fluidized Bed Combustion Combined Wastes: Landfill

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	1.1E+02	1.4E-01	1.1E-04	9.5E-05
Boron	6.2E-04	1.8E-05	6.0E-06	6.0E-06
Cadmium	8.7E-04	1.3E-06	7.9E-09	7.8E-09
Cobalt	1.8E-03	5.3E-06	1.2E-07	1.2E-07
Lead	1.4E-01	2.2E-04	1.8E-08	7.9E-10
Nickel	1.1E-02	2.1E-05	2.6E-07	2.6E-07
Silver	4.2E-06	4.4E-07	1.1E-06	1.1E-06
Thallium	3.3E-03	6.9E-06	9.3E-08	9.3E-08
Vanadium	1.7E-02	4.5E-05	9.0E-07	9.0E-07

Table 6.12 Modeled Concentrations for Constituents in Soil, Sediment, and Surface Water Using Central Tendency Management/Use Scenarios for Fluidized Bed Combustion Combined Wastes: Agricultural Soil Amendment

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	1.8E+00	5.0E-03	3.8E-06	3.4E-06
Boron	2.5E-05	1.1E-08	3.8E-09	3.8E-09
Cobalt	6.4E-05	3.6E-08	8.0E-10	7.9E-10
Nickel	3.6E-04	2.3E-07	2.8E-09	2.8E-09
Thallium	1.1E-04	6.9E-08	9.3E-10	9.3E-10
Vanadium	5.8E-04	3.3E-07	6.6E-09	6.6E-09

Table 6.13 Modeled Concentrations for Constituents in Soil, Sediment, and Surface Water Using Central Tendency Management/Use Scenarios for Non-Utility Coal Co-Managed Wastes: Onsite Landfill

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	1.4E+01	1.9E-02	1.4E-05	1.3E-05
Barium	1.1E-01	1.4E-04	2.8E-07	2.7E-07
Boron	2.2E-04	6.0E-06	2.0E-06	2.0E-06
Cadmium	3.8E-04	5.5E-07	3.5E-09	3.4E-09
Cobalt	6.9E-04	2.0E-06	4.4E-08	4.4E-08
Lead	7.2E-03	1.2E-05	9.9E-10	4.2E-11
Selenium $_{total}$	1.4E-05	2.9E-07	6.8E-08	6.8E-08
Silver	1.8E-06	1.8E-07	4.5E-07	4.5E-07
Thallium	7.3E-04	1.5E-06	2.1E-08	2.0E-08

Table 6.14 Modeled Concentrations for Constituents in Soil, Sediment, and Surface Water Using Central Tendency Management/Use Scenarios for Non-Utility Coal Co-Managed Wastes: Offsite Landfill

Constituent	Soil Concentration (mg/kg)	Sediment Concentration (mg/kg)	Total Surface Water Concentration (mg/L)	Dissolved Surface Water Concentration (mg/L)
Aluminum	2.6E+02	3.3E-01	2.5E-04	2.2E-04
Barium	2.1E+00	2.5E-03	4.8E-06	4.6E-06
Boron	4.0E-03	1.2E-04	3.9E-05	3.9E-05
Cadmium	6.9E-03	9.9E-06	6.2E-08	6.1E-08
Cobalt	1.3E-02	3.7E-05	8.2E-07	8.2E-07
Lead	1.3E-01	2.0E-04	1.7E-08	7.3E-10
Selenium $_{total}$	2.6E-04	5.7E-06	1.3E-06	1.3E-06
Silver	3.2E-05	3.5E-06	8.8E-06	8.8E-06
Thallium	1.3E-02	2.8E-05	3.8E-07	3.8E-07

Table 7.1 Hazard Quotients for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use Scenarios for Utility Coal Co-Managed Wastes: Landfill

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	5.8E-02	--	1.0E-02
Barium	3.9E-01	1.3E-03	1.2E-01	--	--
Boron	--	--	6.3E-01	--	3.5E-05
Cadmium	2.4E-01	5.2E-04	8.9E-04	9.6E-04	1.2E-06
Cobalt	1.4E-04	--	3.9E-04	--	1.8E-04
Lead	2.7E-01	5.4E-02	3.3E-03	1.8E-04	4.7E-07
Selenium $_{total}$	1.1E-01	--	1.1E-01	--	3.6E-04
Silver	--	9.4E-05	1.6E-03	--	1.7E-05
Thallium	--	--	6.0E-04	--	6.5E-05

Table 7.2 Hazard Quotients for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use Scenarios for Utility Coal Co-Managed Wastes: Dewatered Surface Impoundment

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	1.6E-02	--	2.8E-03
Barium	7.6E-02	1.9E-04	1.8E-02	--	--
Boron	--	--	2.2E-03	--	1.2E-07
Cadmium	5.1E-02	4.8E-05	8.2E-05	9.0E-05	1.1E-07
Cobalt	6.9E-05	--	3.7E-05	--	1.7E-05
Lead	4.7E-02	2.2E-02	1.3E-03	7.1E-05	1.9E-07
Selenium $_{total}$	2.4E-02	--	5.4E-04	--	1.7E-06
Silver	--	8.3E-08	4.2E-04	--	4.5E-06
Thallium	--	--	4.7E-05	--	5.1E-06

Table 7.3 Hazard Quotients for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use Scenarios for Utility Oil-Fired Wastes: Onsite Landfill

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	6.1E-04	--	1.1E-04
Arsenic $_{total}$	2.5E-03	1.5E-04	9.5E-05	--	6.4E-07
Boron	--	--	2.0E-03	--	1.1E-07
Cadmium	2.7E-03	6.3E-06	1.1E-05	1.2E-05	1.4E-08
Chromium VI	2.9E-04	4.8E-06	4.1E-04	4.2E-04	--
Cobalt	3.6E-06	--	4.9E-06	--	2.3E-06
Copper	6.8E-03	2.9E-05	2.6E-03	2.7E-03	2.1E-05
Lead	3.5E-02	9.5E-03	5.7E-04	3.1E-05	8.2E-08
Nickel	5.0E-02	1.8E-04	6.6E-04	6.6E-04	1.6E-05
Silver	--	5.4E-07	2.7E-03	--	2.9E-05
Vanadium	4.3E-02	3.8E-04	6.9E-03	--	--
Zinc	1.5E-03	1.6E-06	4.1E-05	4.1E-05	7.5E-07

Table 7.4 Hazard Quotients for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use for Fluidized Bed Combined Wastes: Landfill

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	6.3E-03	--	1.1E-03
Boron	--	--	1.7E-02	--	9.6E-07
Cadmium	1.3E-02	2.7E-05	4.5E-05	4.9E-05	6.0E-08
Cobalt	1.0E-05	--	2.8E-05	--	1.3E-05
Lead	2.9E-02	5.8E-03	3.5E-04	1.9E-05	5.1E-08
Nickel	2.5E-02	9.1E-05	3.4E-04	3.4E-04	8.2E-06
Silver	--	8.1E-06	4.1E-02	--	4.4E-04
Thallium	--	--	7.5E-05	--	8.2E-06
Vanadium	6.4E-02	6.6E-04	1.2E-02	--	--

Table 7.5 Hazard Quotients for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use Scenarios for Fluidized Bed Combustion Combined Wastes: Agricultural Soil Amendment

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	1.9E-04	--	3.3E-05
Boron	--	--	9.2E-06	--	5.1E-10
Cobalt	2.9E-07	--	1.6E-07	--	7.2E-08
Nickel	6.9E-04	8.1E-07	3.1E-06	3.0E-06	7.3E-08
Thallium	--	--	6.2E-07	--	6.8E-08
Vanadium	1.8E-03	4.0E-06	7.2E-05	--	--

Table 7.6 Hazard Quotients for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use Scenarios for Non-Utility Coal Co-Managed: Onsite Landfill

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	1.6E-03	--	2.6E-04
Barium	1.1E-02	3.5E-05	3.3E-03	--	--
Boron	--	--	1.6E-02	--	9.1E-07
Cadmium	6.7E-03	1.4E-05	2.5E-05	2.7E-05	3.2E-08
Cobalt	1.1E-05	--	1.6E-04	--	7.1E-05
Lead	--	--	--	--	--
Selenium $_{total}$	2.4E-02	--	1.2E-04	--	3.7E-07
Silver	--	8.6E-05	4.1E-02	--	4.4E-04
Thallium	--	--	3.7E-04	--	4.0E-05

Table 7.7 Hazard Quotients for Constituents in Soil, Sediment, and Surface Water Using High-End Management/Use Scenarios for Non-Utility Coal Co-Managed Wastes: Offsite Landfill

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	3.2E-02	--	5.5E-03
Barium	2.2E-01	6.9E-04	6.4E-02	--	--
Boron	--	--	3.5E-01	--	2.0E-05
Cadmium	1.4E-01	2.9E-04	4.9E-04	5.3E-04	6.5E-07
Cobalt	7.7E-05	--	2.2E-04	--	1.0E-04
Lead	1.5E-01	3.0E-02	1.8E-03	9.7E-05	2.6E-07
Selenium $_{total}$	6.1E-02	--	6.3E-02	--	2.0E-04
Silver	--	5.3E-05	2.7E-01	--	2.9E-03
Thallium	--	--	3.3E-04	--	3.6E-05

Table 7.8 Hazard Quotients for Constituents in Soil, Sediment, and Surface Water Using Central Tendency Management/Use Scenarios for Utility Coal Co-Managed Wastes: Landfill

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	5.3E-03	--	9.3E-04
Barium	7.5E-03	2.4E-05	2.2E-03	--	--
Boron	--	--	4.4E-02	--	2.4E-06
Cadmium	1.3E-02	2.7E-05	4.6E-05	4.9E-05	6.0E-08
Cobalt	2.3E-05	--	6.5E-05	--	3.0E-05
Lead	8.7E-03	1.7E-03	1.1E-04	5.7E-06	1.5E-08
Selenium $_{total}$	4.8E-04	--	4.7E-04	--	1.5E-06
Silver	--	8.6E-06	4.4E-02	--	4.7E-04
Thallium	--	--	5.8E-05	--	6.3E-06

Table 7.9 Hazard Quotients for Constituents in Soil, Sediment, and Surface Water Using Central Tendency Management/Use Scenarios for Utility Coal Co-Managed Wastes: Dewatered Surface Impoundment

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	9.0E-04	--	1.6E-04
Barium	5.5E-04	3.9E-06	3.6E-04	--	--
Boron	--	--	2.4E-04	--	1.3E-08
Cadmium	9.3E-04	3.3E-06	5.6E-06	6.0E-06	7.3E-09
Cobalt	1.7E-06	--	3.8E-06	--	1.7E-06
Lead	6.3E-04	2.9E-04	1.8E-05	9.7E-07	2.6E-09
Selenium total	3.5E-05	--	3.6E-06	--	1.1E-08
Silver	--	9.0E-09	4.5E-05	--	4.9E-07
Thallium	--	--	4.7E-06	--	5.1E-07

Table 7.10 Hazard Quotients for Constituents in Soil, Sediment, and Surface Water Using Central Tendency Management/Use Scenarios for Utility Oil-Fired Wastes: Onsite Landfill

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	5.6E-05	--	9.7E-06
Arsenic $_{total}$	3.0E-05	2.3E-06	1.4E-06	--	9.5E-09
Arsenic III	3.0E-05	2.3E-06	2.7E-07	2.7E-07	--
Arsenic V	3.0E-05	2.3E-06	5.0E-06	5.0E-06	--
Boron	--	--	1.9E-03	--	1.1E-07
Cadmium	3.3E-04	7.5E-07	1.3E-06	1.4E-06	1.7E-09
Chromium VI	6.4E-05	1.4E-06	1.2E-04	1.3E-04	--
Cobalt	1.4E-06	--	3.9E-06	--	1.8E-06
Copper	3.6E-04	2.0E-06	1.8E-04	1.9E-04	1.5E-06
Lead	4.9E-03	1.0E-03	6.3E-05	3.4E-06	9.0E-09
Nickel	1.2E-02	4.3E-05	1.6E-04	1.6E-04	3.9E-06
Silver	--	1.5E-07	7.5E-04	--	8.1E-06
Vanadium	1.2E-02	1.3E-04	2.3E-03	--	--
Zinc	2.2E-04	2.8E-07	7.1E-06	7.1E-06	1.3E-07

Table 7.11 Hazard Quotients for Constituents in Soil, Sediment and Surface Water Using Central Tendency Management/Use Scenarios for Fluidized Bed Combustion Combined Wastes: Landfill

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	1.2E-03	--	2.1E-04
Boron	--	--	3.7E-03	--	2.1E-07
Cadmium	8.7E-04	1.8E-06	3.1E-06	3.4E-06	4.1E-09
Cobalt	1.8E-06	--	5.1E-06	--	2.4E-06
Lead	5.0E-03	1.0E-03	6.1E-05	3.3E-06	8.8E-09
Nickel	3.6E-04	1.3E-06	5.0E-06	5.0E-06	1.2E-07
Silver	--	6.1E-07	3.1E-03	--	3.3E-05
Thallium	--	--	7.8E-06	--	8.5E-07
Vanadium	2.4E-04	2.5E-06	4.5E-05	--	--

Table 7.12 Hazard Quotients for Constituents in Soil, Sediment, and Surface Water Using Central Tendency Management/USe Scenarios for Fluidized Bed Combustion Combined Wastes: Agricultural Soil Amendment

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	4.317E-05	--	7.547E-06
Boron	--	--	2.380E-06	--	1.311E-10
Cobalt	6.358E-08	--	3.466E-08	--	1.594E-08
Nickel	1.214E-05	1.426E-08	5.353E-08	5.334E-08	1.280E-09
Thallium	--	--	7.768E-08	--	8.474E-09
Vanadium	8.394E-06	1.836E-08	3.317E-07	--	--

Table 7.13 Hazard Quotients for Constituents in Soil, Sediment, and Surface Water Using Central Tendency Management/Use Scenarios for Non-Utility Coal Co-Managed Wastes: Onsite Landfill

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	1.6E-04	--	2.6E-05
Barium	2.2E-04	7.4E-07	6.9E-05	--	--
Boron	--	--	1.3E-03	--	6.9E-08
Cadmium	3.8E-04	8.1E-07	1.4E-06	1.5E-06	1.8E-09
Cobalt	6.9E-07	--	1.9E-06	--	8.7E-07
Lead	2.6E-04	5.4E-05	3.3E-06	4.1E-06	2.0E-11
Selenium $_{total}$	1.4E-05	--	1.4E-05	--	4.3E-08
Silver	--	2.5E-07	1.3E-03	--	1.3E-05
Thallium	--	--	1.7E-06	--	1.9E-07

Table 7.14 Hazard Quotients for Constituents in Soil, Sediment, and Surface Water Using Central Tendency Management/Use Scenarios for Non-Utility Coal Co-Managed Wastes: Off-Site Landfill

Constituent	Soil HQ	Sediment HQ	Total Surface Water HQ	Dissolved Surface Water HQ	Amphibian HQ
Aluminum	--	--	2.8E-03	--	5.0E-04
Barium	4.1E-03	1.3E-05	1.2E-03	--	--
Boron	--	--	2.4E-02	--	1.3E-06
Cadmium	6.9E-03	1.5E-05	2.5E-05	2.7E-05	3.2E-08
Cobalt	1.3E-05	--	3.6E-05	--	1.6E-05
Lead	4.8E-03	9.3E-04	5.7E-05	3.1E-06	8.1E-09
Selenium $_{total}$	2.6E-04	--	2.6E-04	--	8.4E-07
Silver	--	4.8E-06	2.4E-02	--	2.6E-04
Thallium	--	--	3.2E-05	--	3.4E-06

Table 8.1 The 95th Percentile (High-End) Concentration of Constituents Measured in Surface Impoundment Waters from Coal Ash Co-Managed Sites

Constituent	Total Surface Water Concentration (mg/L)	number of sites analyzed
Aluminum	5.1E+00	13
Antimony	1.4E-01	2
Arsenic $_{total}$	5.5E-01	15
Barium	7.1E-01	14
Beryllium	1.0E-03	2
Boron	4.6E+02	16
Cadmium	2.5E-01	14
Chromium $_{total}$	4.0E-01	15
Chromium VI	2.7E-02	1
Cobalt	1.0E-02	2
Copper	3.9E-01	11
Lead	2.5E-01	13
Mercury	1.5E-03	2
Molybdenum	5.0E-01	15
Nickel	6.0E-01	14
Selenium $_{total}$	7.8E+00	13
Silver	5.0E-03	3
Thallium	5.0E-02	2
Vanadium	8.0E-01	14
Zinc	6.7E-01	15

Table 8.2 The Median Concentration (Central Tendency) of Constituents Measured in Surface Impoundment Waters from Coal Ash Co-Managed Sites

Constituent	Total Surface Water Concentration (mg/L)	number of sites analyzed
Aluminum	7.4E-01	13
Antimony	1.2E-01	2
Arsenic $_{total}$	2.0E-02	15
Barium	1.3E-01	14
Beryllium	1.0E-03	2
Boron	5.7E+00	16
Cadmium	8.9E-03	14
Chromium $_{total}$	1.1E-02	15
Chromium VI	2.7E-02	1
Cobalt	7.5E-03	2
Copper	7.7E-03	11
Lead	1.4E-02	13
Mercury	1.0E-03	2
Molybdenum	1.9E-01	15
Nickel	2.4E-02	14
Selenium $_{total}$	4.0E-02	13
Silver	4.3E-03	3
Thallium	2.6E-02	2
Vanadium	3.7E-02	14
Zinc	2.5E-02	15

Table 9.1 Hazard Quotients (High-End) Calculated for Receptors Potentially Exposed to Surface Impoundment Waters from Coal Co-Managed Sites

Constituent	Freshwater Community HQ	Representative Freshwater Wildlife HQ	Amphibian HQ
Aluminum	**5.9E+01**	--	**1.0E+01**
Antimony	**4.6E+00**	2.0E-01	4.6E-01
Arsenic $_{total}$	1.9E+01	**1.9E+01**	1.3E-01
Arsenic III	**3.7E+00**	--	--
Arsenic V	**6.8E+01**	--	--
Barium	**1.8E+02**	3.9E-03	--
Beryllium	**1.5E+00**	--	--
Boron	**2.9E+05**	--	**1.6E+01**
Cadmium	**1.0E+02**	**2.3E+01**	1.3E-01
Chromium	**3.6E+01**	9.6E-02	4.6E-02
Chromium III	--	--	--
Chromium VI	**2.4E+00**	--	--
Cobalt	4.3E-01	--	2.0E-01
Copper	**4.2E+01**	9.9E-03	3.4E-01
Lead	**7.8E+01**	**8.3E+02**	1.2E-01
Mercury	**1.2E+02**	**4.5E+03**	7.3E-03
Methyl mercury	**5.2E+02**	--	--
Molybdenum	**1.4E+00**	1.4E-01	--
Nickel	**1.2E+01**	6.3E-03	2.8E-01
Selenium $_{total}$	**1.6E+03**	**3.0E+04**	**4.9E+00**
Selenium IV	**2.8E+02**	--	--
Selenium VI	**8.2E+02**	--	--
Silver	**1.4E+01**	--	1.5E-01
Thallium	**4.2E+00**	--	4.5E-01
Vanadium	**4.0E+01**	3.1E-01	--
Zinc	**5.6E+00**	7.8E-02	1.0E-01

HQs in the shaded column were derived by comparing surface water CSCLs to measured concentrations of constituents in surface water impoundments. Although aquatic organisms are often found in surface impoundment waters, surface impoundments are not designed to serve as aquatic habitats. Therefore, ratios between effects on aquatic biota and surface impoundment concentrations (i.e., the HQ) were not considered to be indicative of ecological risks.

Table 9.2 Hazard Quotients (Central Tendency) Calculated from for Receptors Potentially Exposed to Surface Impoundment Waters from Coal Co-Managed Sites

Constituent	Freshwater Community HQ	Representative Freshwater Wildlife HQ	Amphibian HQ
Aluminum	**8.5E+00**	--	**1.5E+00**
Antimony	**3.9E+00**	1.7E-01	3.9E-01
Arsenic $_{total}$	6.9E-01	7.1E-01	4.7E-03
Arsenic III	1.3E-01	--	--
Arsenic V	**2.5E+00**	--	--
Barium	**3.4E+01**	7.4E-04	--
Beryllium	**1.5E+00**	--	--
Boron	**3.5E+03**	--	2.0E-01
Cadmium	**3.6E+00**	8.4E-01	4.7E-03
Chromium	**1.0E+00**	2.7E-03	1.3E-03
Chromium III	--	--	--
Chromium VI	**2.4E+00**	6.4E-03	--
Cobalt	3.3E-01	--	1.5E-01
Copper	8.3E-01	2.0E-04	6.8E-03
Lead	**4.2E+00**	**4.5E+01**	6.4E-03
Mercury	**8.3E+01**	**3.1E+03**	5.0E-03
Methyl mercury	**3.6E+02**	--	--
Molybdenum	5.1E-01	5.4E-02	--
Nickel	4.6E-01	2.5E-04	1.1E-02
Selenium $_{total}$	**8.0E+00**	**1.5E+02**	2.5E-02
Selenium IV	**1.4E+00**	--	--
Selenium VI	**4.2E+00**	--	--
Silver	**1.2E+01**	--	1.3E-01
Thallium	**2.2E+00**	--	2.4E-01
Vanadium	**1.9E+00**	1.4E-02	--
Zinc	2.1E-01	2.9E-03	3.8E-03

HQs in the shaded column were derived by comparing surface water CSCLs to measured concentrations of constituents in surface water impoundments. Although aquatic organisms are often found in surface impoundment waters, surface impoundments are not designed to serve as aquatic habitats. Therefore, ratios between effects on aquatic biota and surface impoundment concentrations (i.e., the HQ) were not considered to be indicative of ecological risks.

Table 10. Equations Used to Calculate Food Consumption Rates (F)

For laboratory animals,

Equation number	Food consumption rate	Laboratory parameters	Units for F	Units for body Weight
(1)	$F = 0.056 \times (bw)^{0.661}$	mammals, default	kg/day	kg
(2)	$F = 0.054 \times (bw)^{0.9451}$	mammals, moist diet	kg/day	kg
(3)	$F = 0.049 \times (bw)^{0.6087}$	mammals, dry diet	kg/day	kg

For wildlife species,

Equation number	Food consumption rate	Laboratory parameters	Units for F	Units for body Weight
(4)	$F = 0.235 \times (bw)^{0.822}$	placental mammals	g/day	g
(5)	$F = 0.621 \times (bw)^{0.564}$	rodents	g/day	g
(6)	$F = 0.577 \times (bw)^{0.727}$	herbivores	g/day	g
(7)	$F = 0.492 \times (bw)^{0.673}$	marsupials	g/day	g
(8)	$F = 0.648 \times (bw)^{0.651}$	all birds	g/day	g
(9)	$F = 0.0582 \times (bw)^{0.651}$	all birds	kg/day	kg
(10)	$F = 0.398 \times (bw)^{0.850}$	passerine birds	g/day	g
(11)	$F = 0.301 \times (bw)^{0.751}$	non-passerine birds	g/day	g

Equation Used to calculated W, the water consumption rate[1].

For laboratory animals,

Equation number	Water consumption rate	Laboratory parameters	Units for W	Units for body Weight
(52)	$W = 0.10 \times (bw)^{0.7377}$	mammals, default	L/day	kg
(53)	$W = 0.009 \times (bw)^{1.2044}$	mammals, moist diet	L/day	kg
(54)	$W = 0.093 \times (bw)^{0.7584}$	mammals, dry diet	L/day	kg

For Wildlife species,

Equation number	Food consumption rate	Laboratory parameters	Units forW	Units forbody Weight
(55)	$W = 0.099 \times (bw)^{0.90}$	wildlife species	L/day	kg
(56)	$W = 0.059 \times (bw)^{0.67}$	wildlife species	L/day	kg

F = food consumtion rate (mass of food / unit of time)
W = water consumption rate (volume of water / unit of time)
bw = body weight (mass)

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[1] EPA, 1993. *Wildlife Expsoure Factors Handbook.* (vol. I and II). Office of Research and Development. EPA 600/R-93/187.

Table 11.1. Representative Piscivorous Species in the Freshwater Ecosystem

Representative Species	Body Weight (kg)		Water Intake (L/d)		Food Intake (kg/d)		Spring/Summer Diet Consumption (% vol.)
Mink							100% fish (trophic level 3)
female	0.70		0.05		0.11		
male	1.34		0.13		0.21		
both	1.02		0.081		0.16		
River otter							100% fish (0.5 trophic level 3) (0.5 trophic level 4)
female	7.32		0.60		1.18	a	
male	8.67		0.69		1.35	a	
both	7.99		0.65		1.26	a	
Bald eagle							100% fish (trophic level 4)
female	4.50		0.16		0.54	c	
male	3.00		0.11		0.36	c	
both	3.75		0.14		0.45		
Osprey							100% fish (trophic level 3)
female	1.77		0.09		0.37		
male	1.43		0.08		0.30	d	
both	1.63		0.08		0.34	d	
Great blue heron							100% fish (trophic level 4)
female	2.20		0.10	e	0.40	c	
male	2.58		0.12	e	0.46	c	
both	2.34		0.11		0.42		
Mallard							100% aquatic invertebrates (trophic level 2)
female	1.11		0.06		0.31	b	
male	1.24		0.07		0.33	b	
both	1.16		0.07		0.32	b	
Lesser scaup							100% aquatic invertebrates (trophic level 2)
female	0.73		0.05		0.24	b	
male	0.86		0.05		0.26	b	
both	0.75		0.05		0.24	b	
Kingfisher							100% fish (trophic level 3)
female	0.15	f	0.02	e	0.07	c	
male	0.15	f	0.02	e	0.07	c	
both	0.15		0.02		0.07		
Spotted sandpiper							100% aquatic invertebrates (trophic level 2)
female	0.05		0.01		0.03	b	
male	0.04		0.01		0.03	b	
both	0.04		0.01		0.03	b	
Herring Gull							100% fish (trophic level 3)
female	0.98		0.06		0.19		
male	1.21		0.07		0.24		
both	1.09		0.06		0.21		

a = wet weight based on allometric equation for dry matter ingestion for eutherian mammals (Nagy, 1987): 0.235(bw in gms)^0.82
b = wet weight based on allometric equation for dry matter ingestion for all birds (Nagy, 1987): 0.648(bw in gms)^0.651.
c = reported food intake rate was not gender specific
d = female osprey food intake rate was used to estimate food intake rate
e = reported water intake rate was not gender specific
f = reported body weight was not gender specific

Unless otherwise indicated, all values are taken from EPA, 1993. *Wildlife Exposure Factors Handbook* (vol I and II). Office of Research and Development, Washington DC. EPA/600/R-93/187

Table 11.2. Bioaccumulation Factors and Bioconcentration Factors for the Generic Freshwater Ecosystem

Constituent	BCF or BAF	dissolved or total	muscle or whole-body	trophic level 2 invertebrates	trophic level 3 fish	trophic level 4 fish	RBAF (4/3)	Reference
Antimony	BCF	t	whole	ID	0	0	1.00	Stephan, 1993
Arsenic	BCF	t	whole	ID	3.46	3.46	1.00	Stephan, 1993
Barium				ID	ID	ID	--	
Beryllium	BCF	t	whole	ID	19	19	1.00	Barrows et al., 1980
Boron				ID	ID	ID	--	
Cadmium	BCF	t	whole	ID	265	265	1.00	Kumada, 1973
Chromium	BCF	t	whole	ID	1	1	1.00	Stephan, 1993
Cobalt				ID	ID	ID	--	
Copper	BCF	t	muscle	ID	0	0	1.00	Stephan, 1993
Lead	BAF	t	whole	ID	45.7	45.7	1.00	Stephan, 1993
Mercury	BAF	t	whole	ID	66,200	335,000	5.06	EPA, 1996
Molybdenum				ID	ID	ID	--	
Nickel	BCF	t	whole	ID	0.80	0.80	1.00	Stephan, 1993
Selenium	BAF	t	muscle	ID	485	1,692	3.49	Lemly, 1985
Silver	BCF	t	whole	ID	0	0	1.00	Stephan, 1993
Thallium				ID	ID	ID	--	
Vanadium				ID	ID	ID	--	
Zinc	BCF	t	whole	ID	4.4	4.4	1.00	Murphy et al., 1978

Table 12.1. Exposure Inputs for Representative Species in the Terrestrial Ecosystem

Representative Species	Body Weight (kg)	Soil Intake		Food Intake (kg/d)		Spring/Summer Diet Consumption (% vol.)
		% of diet	kg/d			
Short-tailed shrew						13% plants
female	0.017	1	9.4E-05	0.0094		31% earthworms
male	0.017	1	9.5E-05	0.0095		39% invertebrates
both	0.017	1	9.2E-05	0.0092		
Deer mouse						44% plants
female	0.019	2	7.1E-05	0.0035		43% invertebrates
male	0.020	2	8.8E-05	0.0044		
both	0.019	2	7.4E-05	0.0037		
Meadow vole						98% plants
female	0.039	2.4	3.0E-04	0.013		2% invertebrates
male	0.043	2.4	3.3E-04	0.014		
both	0.033	2.4	2.6E-04	0.011		
Eastern cottontail						100% plants
female	1.22	6.3	6.4E-03	0.10	a	
male	1.13	6.3	6.0E-03	0.10	a	
both	1.22	6.3	6.4E-03	0.10	a	
Red fox						4% plants
female	4.04	2.8	8.1E-03	0.29		96% vertebrates
male	5.04	2.8	1.0E-02	0.36		
both	4.54	2.8	1.2E-02	0.43		
Raccoon						29% plants
female	4.71	9.4	2.3E-02	0.25	b	52% invertebrates
male	6.22	9.4	2.9E-02	0.31	b	10% vertebrates
both	5.62	9.4	2.7E-02	0.28	b	
White-tailed deer						100% plants
female	76.00	2	4.1E-02	2.04	a	
male	110.00	2	5.3E-02	2.67	a	
both	85.00	2	4.4E-02	2.21	a	
Red-tailed hawk						100% vertebrates
female	1.20	1	1.3E-03	0.13		
male	1.06	1	1.1E-03	0.11		
both	1.13	1	1.1E-03	0.11		
American kestrel						49% invertebrates
female	0.13	1	3.7E-04	0.037	c	51% vertebrates
male	0.11	1	3.4E-04	0.034		
both	0.12	1	3.6E-04	0.036		
Northern bobwhite						87% plants
female	0.17	9.3	1.2E-03	0.013	c	13% invertebrates
male	0.16	9.3	1.2E-03	0.013	c	
both	0.17	9.3	1.3E-03	0.014		
American robin						11% plants
female	0.082	1	9.9E-04	0.10	c	89% invertebrates
male	0.082	1	9.9E-04	0.10	c	
both	0.081	1	9.8E-04	0.10		
American woodcock						(summer diet)
female	0.20	10.4	1.6E-02	0.16	c	68% earthworms
male	0.15	10.4	1.2E-02	0.12	c	11% plants
both	0.17	10.4	1.3E-02	0.13		20% invertebrates

a = food consumption rate for dry matter ingestion is based on the equation F=0.577(bw)^0.727 (Nagy, 1987)
b = food consumption rate for dry matter ingestion is based on the equation F=0.235(bw)^0.822 (Nagy, 1987)
c = reported food intake rate was not gender specific.

Unless otherwise indicated, all input values are taken from EPA, 1993. *Wildlife Exposure Factors Handbook* (vol. I and II). Office of Research and Development, Washington DC. EPA/600/R-93/187.

Table 12.2. Bioconcentration Factors for the Generic Terresterial Ecosystem

Constituent	Worms	Reference	Invertebrates	Reference	Vertebrates	Reference	Plants	Reference
Aluminum	ID		ID		ID		ID	
Antimony	ID		ID		ID		ID	
Arsenic	5.2E-01	Sample et al., 1998b	ID		1.5E-02	Sample et al., 1998a	1.2E+00	Sample et al., 1997
Barium	ID		ID		1.1E-01	Sample et al., 1998a	ID	
Beryllium	ID		ID		ID		ID	
Boron	ID		ID		ID		ID	
Cadmium	4.1E+01	Sample et al., 1998b	ID		4.0E+00	Sample et al., 1998a	4.6E+00	Sample et al., 1997
Chromium	3.2E+00	Sample et al., 1998b	ID		3.3E-01	Sample et al., 1998a	ID	
Cobalt	ID		ID		1.0E-01	Sample et al., 1998a	ID	
Copper	1.5E+00	Sample et al., 1998b	ID		1.0E+00	Sample et al., 1998a	1.5E+00	US EPA, 1992
Lead	1.5E+00	Sample et al., 1998b	ID		2.9E-01	Sample et al., 1998a	6.2E-01	Sample et al., 1997
Mercury	2.1E+01	Sample et al., 1998b	ID		1.9E-01	Sample et al., 1998a	ID	
Molybdenum	ID		ID		ID		ID	
Nickel	4.7E+00	Sample et al., 1998b	ID		5.9E-01	Sample et al., 1998a	1.7E+00	Sample et al., 1997
Selenium	1.3E+00	Sample et al., 1998b	ID		1.2E+00	Sample et al., 1998a	2.6E+01	Sample et al., 1997
Silver	ID		ID		ID		ID	
Thallium	ID		ID		1.2E-01	Sample et al., 1998a	ID	
Vanadium	ID		ID		ID		ID	
Zinc	1.3E+01	Sample et al., 1998b	ID		2.7E+00	Sample et al., 1998a	2.8E+00	US EPA, 1992

ID: insufficient data
NR: Not reported

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